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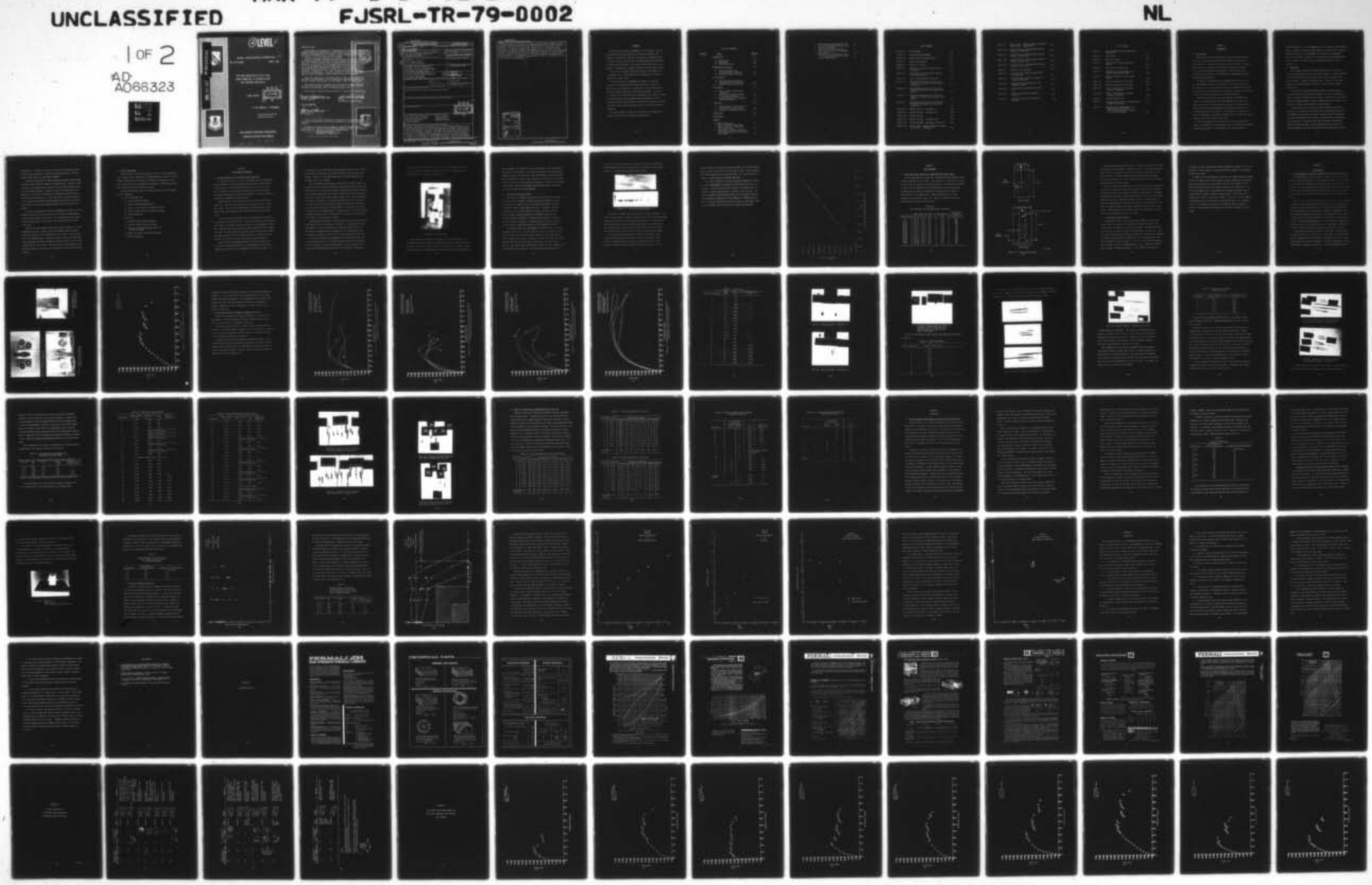

FRANK J. SEILER RESEARCH LABORATORY

SRL-TR-79-0002 MARCH 1979

TEST AND EVALUATION OF SPLIT RING SHEAR CONNECTORS IN LAMINATED WOOD AND LAMINATED WOOD BOLTS

FINAL REPORT

LT COL DWAYNE D. PIEPENBURG

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FJSRL-TR-79-0002

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This paper describes the procedures used to establish the strength of 4 inch diameter beveled TECO split-ring shear connectors in PERMALI laminated wood gusset plate material. Fifty-one specimens were tested with varying combinations of end and edge distances. The effect of surface grain orientation to direction of loading was also investigated. Test data for split-ring shear connectors are presented as load-deformation curves. Ultimate load capacity is shown to be a function of end and edge distance but relatively independent of surface grain orientation to direction of loading. End and edge distances over

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20. greater than 3.5 inches do not appear to significantly increase the shear strength of the split-ring connector. Laminated wood bolts having a nominal diameter of 3/4 inch were tested under various states of combined stress. Test data is presented in tabular and graphical form. The bolts are shown to behave as a bilinear material with independent ultimate tensile and torsional stresses. The most frequent failure mode was the shearing off of the threads on the wood bolts. After applying a load duration factor for testing and a factor of safety of 2, allowable design loads of 1600 lb in tension and 9.5 ft-lb in torsion are recommended.

FOREWORD

This report was prepared by members of the Department of Civil Engineering, Engineering Mechanics and Materials (DFCEM), USAF Academy, Colorado. This work was initiated as an unfunded project in support of the construction of the TRESTLE structure at Kirtland Air Force Base, New Mexico. The project investigators were Lt Col Dwayne D. Piepenburg, Maj Dabney S. Craddock and Capt Dennis Topper.

The work was accomplished during the period of September 1977 to September 1978. This manuscript was released by the author for publication in March 1979.

The author wishes to acknowledge the support of personnel assigned to the TRESTLE Project Office for their assistance in obtaining the test materials. Specifically, Lt Col Douglas Merkle and Capt Michael Schmidt for their help and guidance. The author is indebted to Mr. John Slocum, Mr. Jack Whelton, Mr. Thomas D. Fultz, and Master Sergeant Glenn Kaneyuki from the Department of Civil Engineering, Engineering Mechanics and Materials Laboratory for their assistance with the fabrication and testing of the many laboratory specimens.

The author wishes to thank Mrs. Rita Bauer for her dedicated efforts in proofing and finalizing the manuscript.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This technical report describes the series of tests which were conducted at the United States Air Force Academy to gain a better understanding of the behavior of split-ring shear connectors in laminated wood and to determine the strength of laminated wood bolts. Fifty one split-ring shear specimens and 111 bolt specimens were tested in the Department of Civil Engineering, Engineering Mechanics and Materials laboratories.

The project was sponsored by the TRESTLE project office of the Air Force Weapons Laboratory at Kirtland Air Force Base, New Mexico. All materials used in the tests were selected at random from the field construction site and are believed to adequately represent the materials used in the actual construction of the TRESTLE structure.

English units of measure are used exclusively throughout this report. The principle reason for using English units is that the materials tested are conventional items used in the construction industry and are sold by manufacturers using English dimensions, i.e., a 4" TECO split-ring shear connector. In addition, the construction crews use instruments calibrated in English units to control the torque applied to the bolts tested in this study.

The tests conducted in this study were for the most part performed in accordance with the American Society for Testing and Materials established procedures. Some deviations from these proceduress

were necessary due to the non-homogeneity of the laminated wood materials tested. Methods for placing a given torque into bolts prior to testing in tension had not to the knowledge of the author been established prior to these tests. Therefore, it is believed that the methods specified in Chapter 2 of this report are unique and probably the first published.

1.2 Background

Heavy timber construction frequently requires that large shear forces be transferred between the structural members. In many instances, steel split-ring shear connectors have been used in conjunction with gusset plates to transfer these shear forces. Generally, the gusset plates and structural members are mill-cut timbers having standard nominal sizes.

With the advent of glued laminated timber, structural members can be fabricated to span greater distances and to carry significantly heavier loads than standard mill-cut timbers. When constructing facilities with oversized members, special consideration must be given to the transfer of shear forces between structural elements.

The method used by the Air Force Weapons Laboratory in the construction of a large wood test platform and aircraft approach ramp for the TRESTLE Project consisted of glued laminated timber truss members with specially laminated gusset plates in conjunction with split-ring shear connectors. The gusset plates were fabricated from multiple layers of beech wood which had been impregnated under vacuum with a special synthetic resin and then densified by the application of heat

and pressure. The grain of each layer of beech wood alternately cross at 90° to give strength for a variety of loading directions. The material is sold under the trade name of PERMALI.

The American Institute of Timber Construction (AITC) has published allowable loads for shear connectors in seasoned wood. As part of their procedures for designing shear connectors, AITC includes minimum values for end and edge distances. Limited testing by the manufacturer and personnel at the Weapons Laboratory gave preliminary indications that the load carrying capacity of a 4-inch TECO split-ring shear connector in the laminated wood gusset plates exceeded the capacity of the split-ring connector in the glued laminated lumber used for the main truss members.

To reduce the quantity of steel in the TRESTLE structure, 0.75 inch diameter wood bolts were used to secure the structural timber members, split-rings and timber gusset plates. Two laminated wood nuts, having nominal thicknesses of 1 inch and 0.5 inch, were placed on each end of the bolt.

Wood, by the very process with which it grows in nature, is a non-homogeneous material. However, wood has excellent tensile strength properties parallel to the longitudinal axis of growth. The wood bolts used in the TRESTLE Project consisted of layers of beech wood which had been impregnated with resins, densified and then laminated to the longitudinal direction of the bolt. When the wood nuts are tightened to the specified torque, the wood bolts are subjected to tensile and torsional stresses.

1.3 Project Objectives

The objectives of this project were two fold. The first objective was to develop a more complete set of load-deformation curves for 4-inch diameter TECO split-ring connectors in laminated wood material. The second objective was to investigate the strength of laminated wood bolts under combined tensile and torsional stresses.

These principal objectives were further divided into the following areas of importance.

a. Split-Ring Shear Tests
   1) Average Ultimate Strength
   2) Shape of Load-Deformation Curve
   3) Effect of End Distance on Ultimate Strength
   4) Effect of Edge Distance on Ultimate Strength
   5) Failure Mechanism

b. Bolt Tests
   1) Average Ultimate Tensile Strength
   2) Average Ultimate Torsional Strength
   3) Interaction Diagram Relating Tensile and Torsional Strength
   4) Effect of Moisture on the Bolt Strength
   5) Failure Mechanism

CHAPTER 2

EXPERIMENTAL PROCEDURES

2.1 Testing Procedures for Split-Ring Shear Connectors

The American Society for Testing and Materials has an established "Standard Methods for Testing Metal Fasteners in Wood," ASTM D1761-68. For the most part, the testing procedures used in this study follow those of the ASTM. The following paragraphs discuss any deviations and unique requirements included in the testing of the split-ring shear connectors in laminated wood gusset plates.

Standard beveled 4-inch TECO split-rings were used as the shear connectors. Bolt holes and grooves for the connectors were cut using TECO cutters. Due to the increased density and the presence of heat-cured resins, carbide cutting tips were used with the standard TECO cutter.

In accordance with paragraph 23.3.3 of ASTM D1761-68, the nuts on the bolts were "finger tight" only. Because the TRESTLE Project involves the testing of aircraft electrical systems in an electromagnetic environment, laminated wood bolts and nuts and fiber reinforced plastic washers were used. The three plates and the split-ring connectors were aligned and properly seated by pressing them together in a hydraulic testing machine. Then the bolt, washers, and nuts were hand-assembled.

Wood which has been impregnated with resin and then heated and densified is generally considered to be *dimensionally stable* and not significantly affected by local changes in air moisture content. For

this reason, no tests were made for wood moisture content and no controls were placed on the elapsed time between specimen preparation and final testing. However, all specimens were kept in the same laboratory environment until final testing.

Each test specimen consisted of three plates as shown in Figure 2-1. Because the ends of the gusset plates in the actual structure do not have confining forces, the two outside plates (representing the gusset plates) were partially supported at the bottom to allow the area below the split-ring core to freely shear upon reaching ultimate load. The center plate was loaded in compression. The split-ring connectors were located near the bottom of the center drive plate, thereby leaving more material between the split-ring and the loading surface, and insuring that failure occurred in the two outside plates. Specimens were cut from larger plates of laminated material with the surface grain of the wood oriented at 0°, 45°, or 90° to the direction of loading.

Deformations were measured on both sides of the test specimens using dial indicators with a resolution of 0.001 inch. The amount of slip or deformation in the joint between each of the side plates and the center plate was measured from the beginning of the application of load as opposed to setting the dials to zero at some specified initial load.

The rate of loading was established using the ASTM guidelines for conducting each test so as to achieve maximum load in about 10 minutes, but not less than 5 or more than 20 minutes, as the more important criteria than the ASTM specified load rate of 0.035 in/min $\pm$ 50 percent.

A load rate of 0.016 in/min was selected. This rate provided sufficient time for accurately recording deformation data and for completing each test within 10 to 12 minutes of elapsed time.

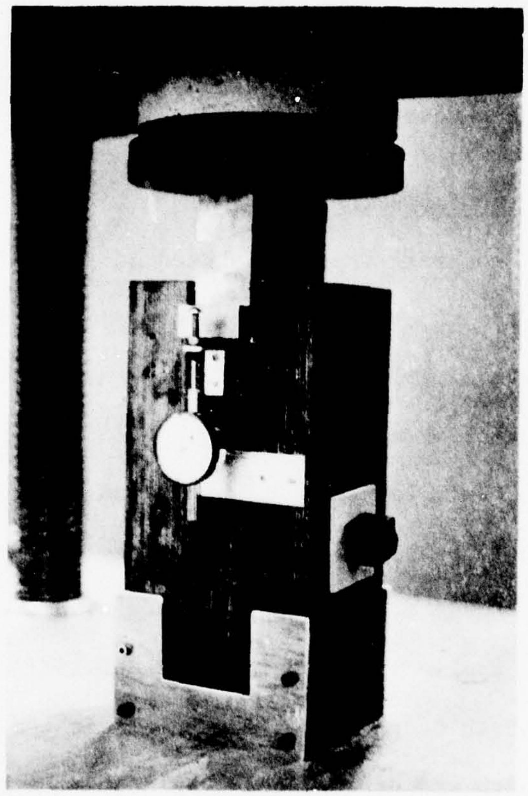


Figure 2-1. Test Specimen

Three persons were required to properly record the test data. Two individuals read and recorded the deformation data and the third individual served as test leader, machine operator, and recorder of load data. During the initial stages of each load test, data was recorded for each 4000-pound

load increment. As the failure load was approached, the load increment was reduced to 2000 pounds. In addition, as cracks in the specimen and changes in applied load occurred, special intermediate load and deformation readings were recorded. Upon completion of each test, the deformation data from the two dial gages were averaged. In addition, the applied load data was adjusted in accordance with the most recent calibration curve for the universal testing machine.

2.2 Testing Procedures for Bolts

Three basic but separate tests were used as part of this program to obtain tensile strength, torsional strength and combined tensile and torsional strength of bolts. To establish the tensile strength, a universal tensile testing machine was used. Because it appeared desirable to test the full length bolt and it was not possible to use the standard specimen holders on the machine, the bolts were extended through the heads of the machine, nuts placed on the bolts and the tensile load applied. A special block of laminated wood was used to provide a smooth bearing area for the laminated wood nuts.

Torsional strength was established by placing the bolt in a holder as shown in Figure 2-2. Two full thickness nuts were attached to each end of the bolt with sufficient space between the bolt holder and the nuts to permit free rotation. One end of the bolt was held with a wrench and the other end was turned with a calibrated torque wrench until failure. The torque wrench consisted of a solid steel bar to which four strain gages had been applied. The output from these gages was fed

to a strip chart recorder where the output was recorded in millivolts. The peak output was then used along with the calibration curve shown in Figure 2-3 to establish the maximum applied torque.

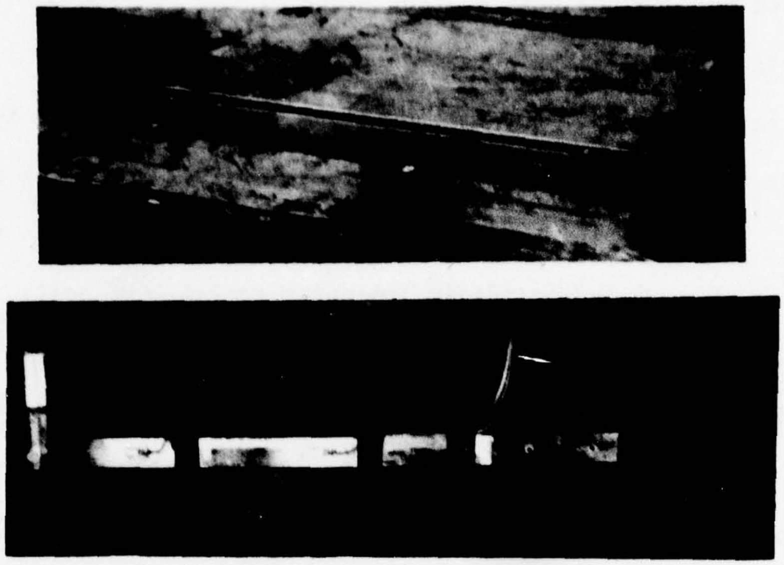


Figure 2-2. Torsion Testing Equipment

Two types of combined tension and torque tests were conducted. The first testing procedure consisted of placing a bolt in the tensile machine, placing two full nuts on each end and then placing a set torque in the bolt with the electronically calibrated torque wrench. The bolt was then pulled with the tensile testing machine until failure occurred. The results of these tests were used to draw the interaction diagram.

In the second testing procedure, the bolts were placed in the tensile testing machine with only one full nut on each end. These nuts were tightened with the torque wrench against the head of the tensile testing machine until failure occurred in the bolt. At the

time of failure, the tensile load was recorded on the tensile machine and the torque recorded on the strip chart recorder. Plastic washers were placed between the nuts and the heads of the tensile machine to reduce friction during the torquing operations.

The rate of loading for all tests involving tension was adjusted to require approximately 10 minutes to develop failure in the bolt specimen. For tests involving pure torsion, the loading rate was adjusted to require approximately 2 minutes to fail the bolt. The change in length of approximately one half of the tension specimens was estimated by measuring the total quantity of loading head movement. It was not considered accurate to measure a small gage length as failure almost always occurred at the end of the specimen.

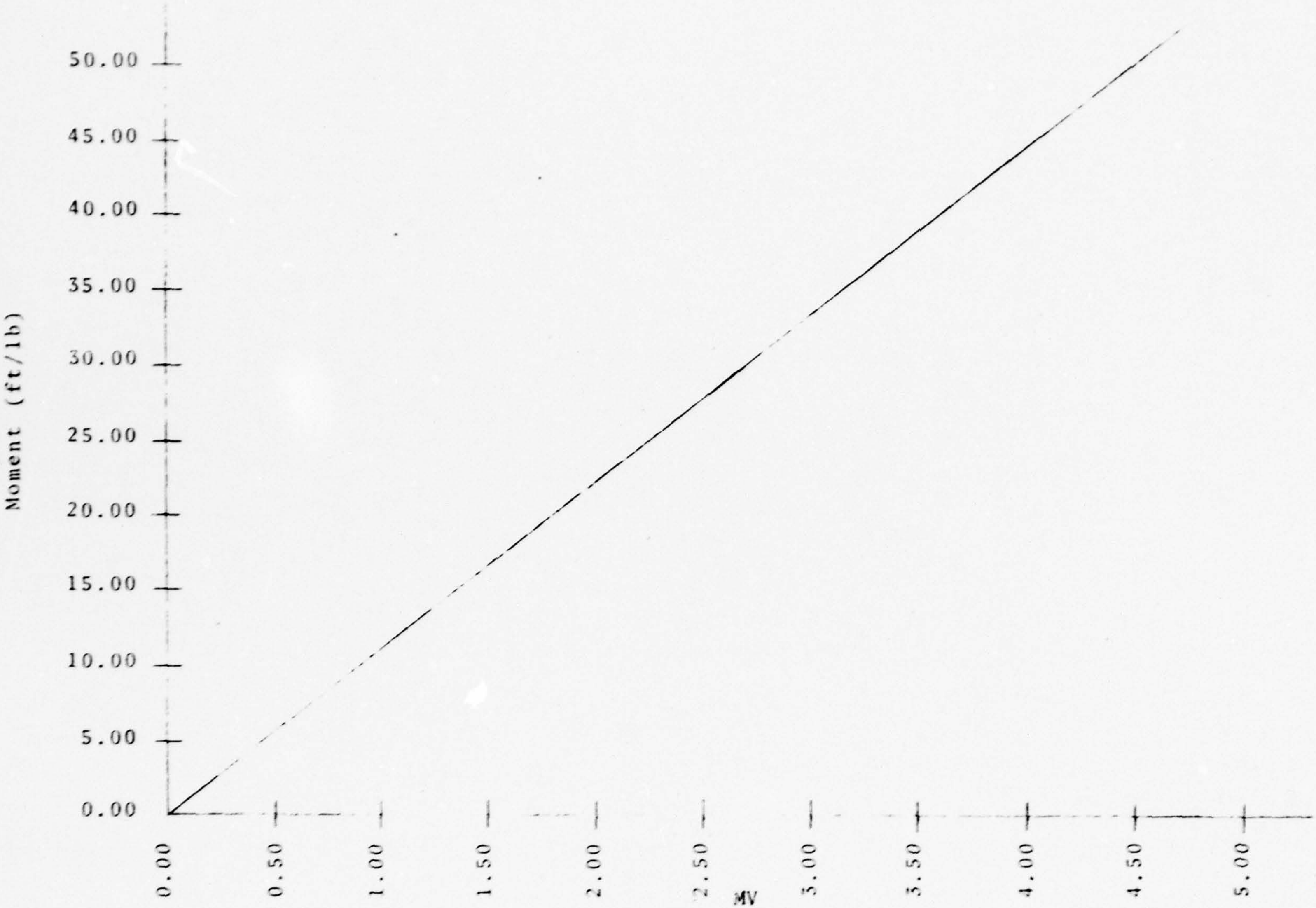


Fig 2-3: Torque Wrench Calibration Curve

CHAPTER 3

TEST SPECIMENS

3.1 Split-Ring Shear Connectors in Laminated Wood Gusset Plates

All test specimens were fabricated from laminated wood material having a nominal thickness of 2.25 inches. The direction of the grain of the wood in each layer was alternated by the manufacturer in the fabrication process. A total of 51 test specimens were fabricated with varying end and edge distances and with varying surface grain orientations with respect to the direction of the applied load. Complete dimensions of all test specimens are presented in Table 3-1. Figure 3-1 defines end and edge distance as used in this series of tests.

Table 3-1

Test Specimens With Split-Ring Shear Connectors

Specimen No.	Length (in)	Width (in)	End Distance (in)	Edge Distance (in)	Surface Grain Oriented To Applied Load
1-5	11.5	5.5	2.5	2.75	90°
6-10	11.5	5.5	3.0	2.75	90°
11-15	11.5	5.5	3.5	2.75	90°
16-20	11.5	5.5	4.0	2.75	90°
21-22	11.5	5.5	2.5	2.75	0°
23-24	11.5	5.5	3.0	2.75	0°
25-26	11:5	5.5	3.5	2.75	0°
27-28	11.5	5.5	4.0	2.75	0°
29-30	11.5	5.5	2.5	2.75	45°
31-32	11.5	5.5	3.0	2.75	45°
33-34	11.5	5.5	3.5	2.75	45°
35-36	11.5	5.5	4.0	2.75	45°
37-41	10.125	6.0	4.0	3.0	90°
42-46	10.125	7.0	4.0	3.5	90°
47-51	10.125	8.0	4.0	4.0	90°

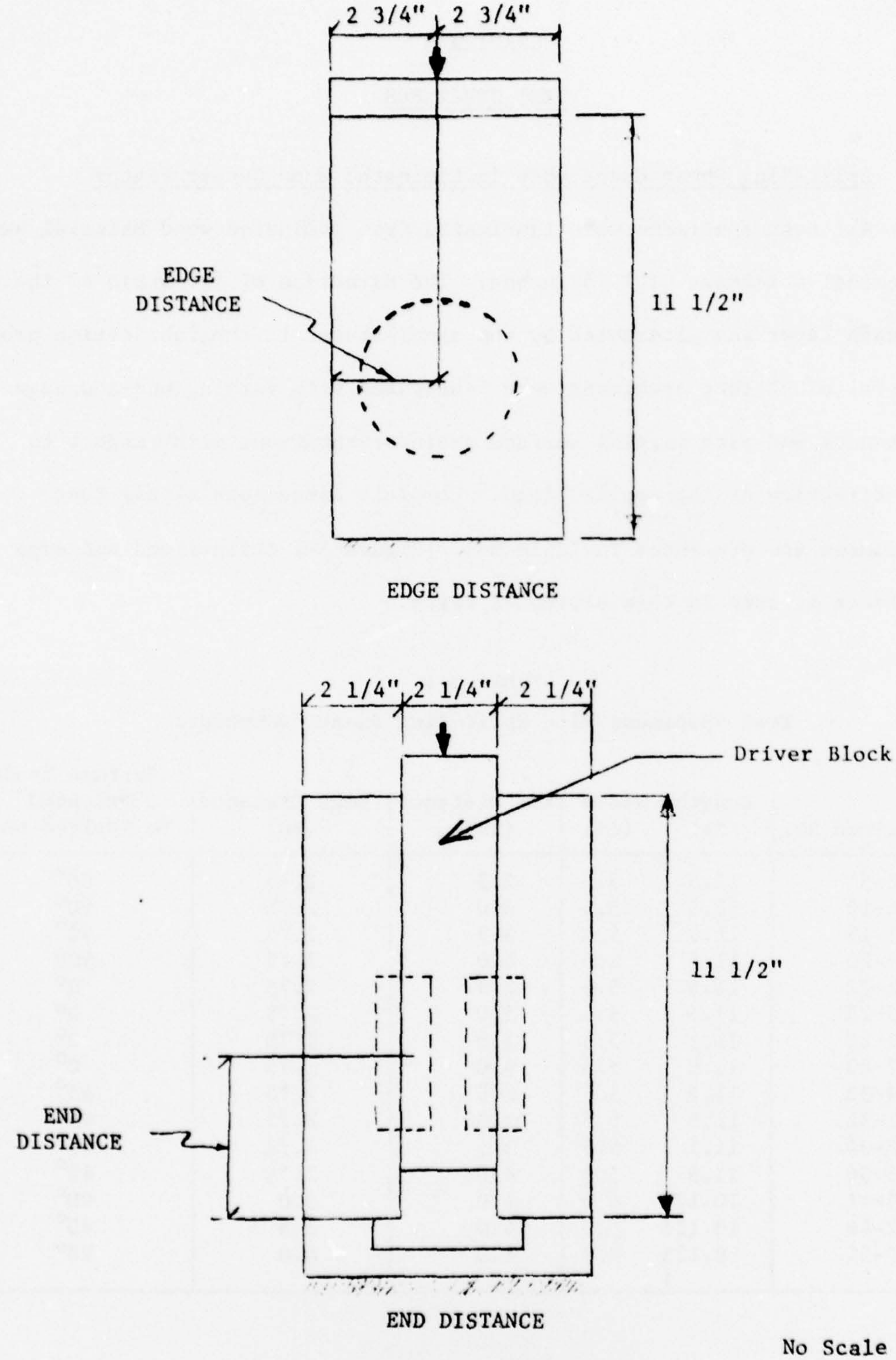


Figure 3-1: Edge and End Distance

Each specimen was prepared by drilling a 0.78125 inch hole and cutting 0.5 inch deep circular grooves 4 inches in diameter at the proper location. A TECO cutter with carbide tips was used to insure a proper fit for the steel split-ring. Careful inspection of the test specimens indicated that the last layer of wood cut by the TECO cutter had a grain orientation perpendicular to the surface grain.

Once the specimens had been cut, the steel split-ring shear connectors were placed in the grooves and properly seated by pressing the laminated wood blocks together in a hydraulic universal testing machine. Following this operation, each specimen was bolted together with a 0.75 inch diameter laminated wood bolt. Laminated wood nuts used to secure the bolts in place were approximately 1.25 inches square and 1.125 inches thick. Fiber reinforced plastic washers were used to separate the nuts from the side plates. These washers were 3.0 inches square and .018 inches thick with a 0.85 inch diameter bolt hole at the center.

3.2 Laminated Wood Bolts and Nuts

Approximately 120 0.75 inch diameter EH57 PERMALI laminated full thread bolts were selected at random from the large stockpile at the project site. The bolts were 31 inches in length. Sufficient wood nuts were selected at random to provide unused materials for each test. Prior to testing, manufacturers published literature was obtained which suggested an ultimate tensile strength of 5500 lb for fully threaded rod or bolts and an ultimate torsional strength of 31 ft lb. This torsional strength was calculated from the following equation: $T_{ult} = 4500 \text{ psi } (0.196\ d^3)$ where d equals the maximum diameter. If the thread root diameter of

.62 inches is used, the ultimate torsional strength is reduced to 17.5 ft lb. Therefore, one would expect the average torsional strength to be somewhere between these limits.

According to the manufacturers literature, the ultimate tensile strength of the core material will usually exceed the shear strength of the threads. This may be assessed on the calculated area πDL of the cylinder at the base of the thread which will be sheared when the nut is pulled off. For 0.75 inch diameter bolts, the manufacturers literature indicated that an ultimate shear strength of 2500 psi should be used. The ultimate load capacity for a full and a half nut is $2500 \times \pi \times .62\ (.63 + 1.13) = 8603$ lb. The manufacturer also states that for most applications, a nut thickness (L) of 1 1/2 D should be sufficient to develop the tensile strength of the bolt. The manufacturers literature is attached as Appendix A to this report.

CHAPTER 4

TEST RESULTS

4.1 Shear Strength of Split-Ring Connectors in Laminated Gusset Plates

Each specimen was tested to failure. Failure, as used here, means that the core of wood within the split-ring had sheared, the wood outside and below the ring had sheared, cracking was very obvious and, most importantly, the load carrying capacity of the joint was rapidly decreasing. In most tests, the wood bolt was not failed as the split-ring connector had distorted significantly and the laminated wood had developed large cracks.

After removing each specimen from the test device, it was disassembled, the depth of failure plane measured from the inside face of each outer plate, and a general description of each failure plane was recorded. Typical descriptions of the failure are tabulated in Appendix B. The failures which accompanied the ultimate load consisted of shear along a vertical plane of the core area within each of the two split-ring connectors. Continued loading produced a shearing along the laminations below the core area, accompanied by an end or edge split. Figures 4-1, 4-2 and 4-3 depict the general appearance of the failure surfaces.

Load-deformation data was plotted for each test. A typical curve is shown in Figure 4-4. The full set of data curves for each specimen, and the consolidated best-fit 5th order polynomial curves for each end distance and surface grain orientation, are shown in Appendices C and D, respectively. A graphical comparison of load vs deformation for end

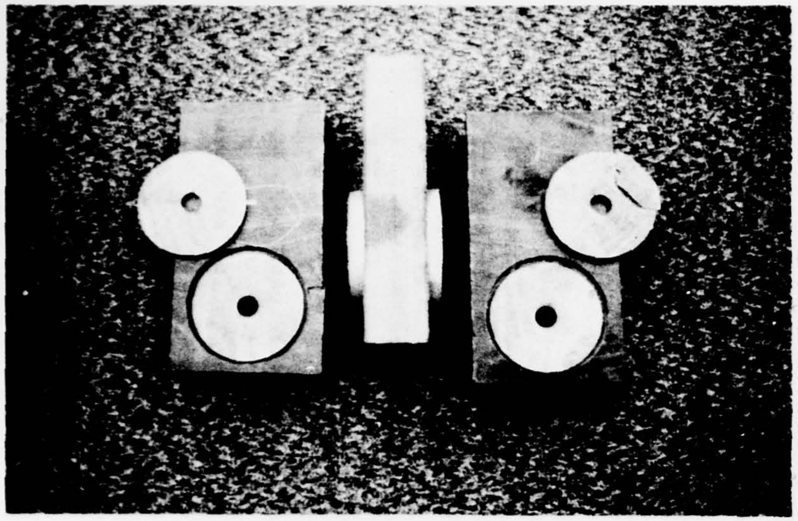


Fig 4-1: Failure of Core Area

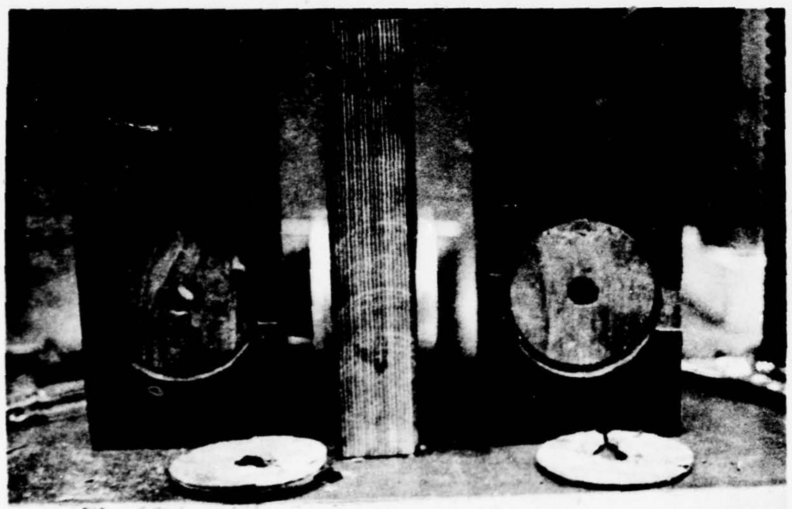


Fig 4-2: Failure of Core Area and Tension Split Along Side

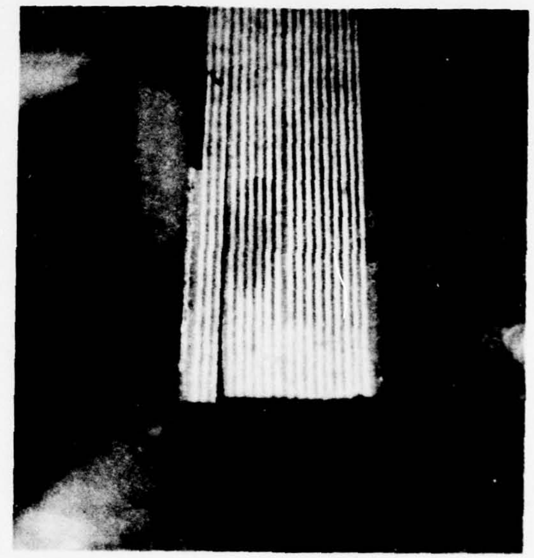


Fig 4-3: Shear Failure of Wood Material Outside Split-Ring Connector

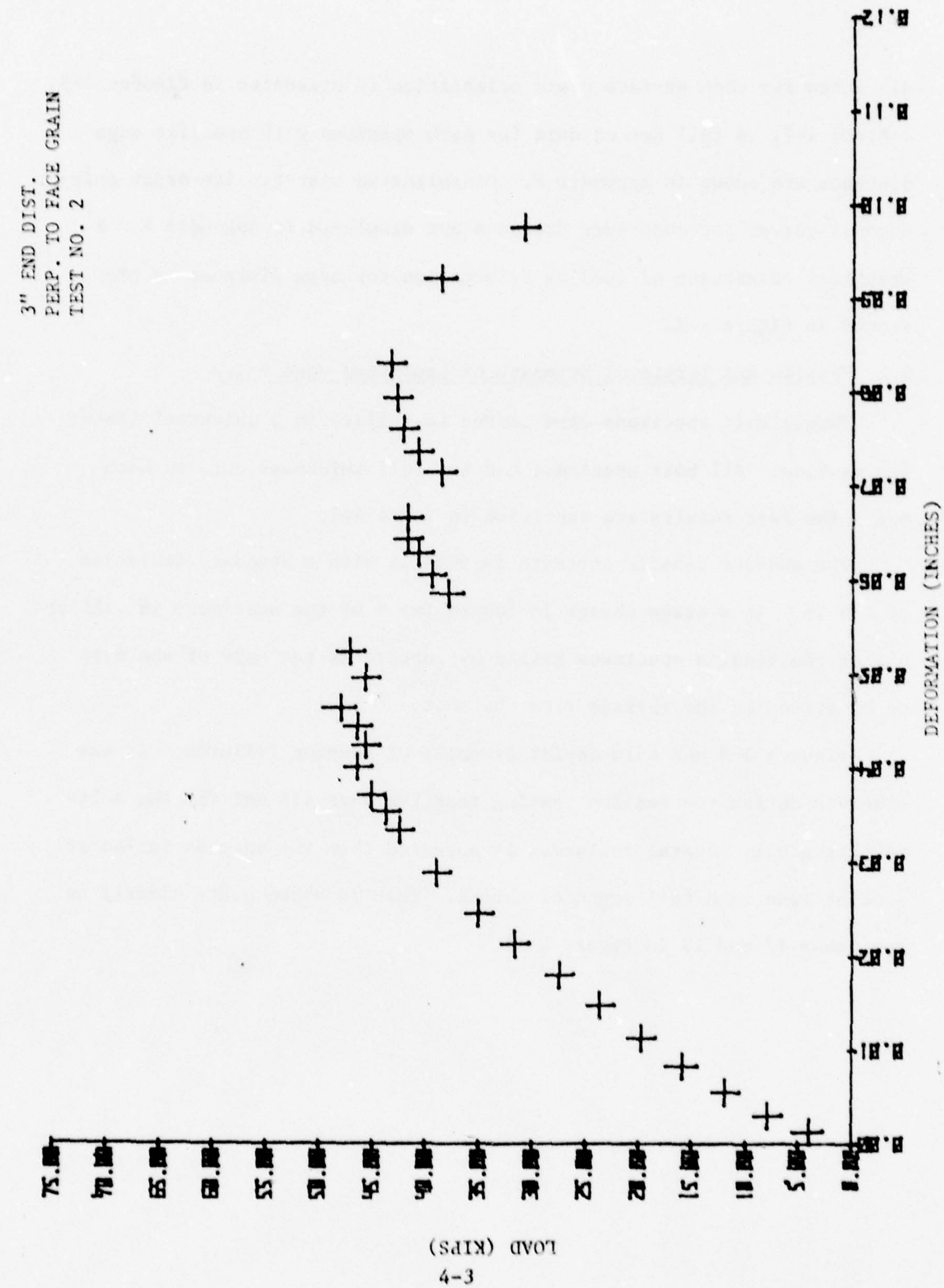


Figure 4-4: Typical Load-Deformation Data Plot

distances for each surface grain orientation is presented in Figures 4-5, 4-6 and 4-7. A full set of data for each specimen with specific edge distance are shown in Appendix E. Consolidated best-fit 5th order polynominal curves for each edge distance are displayed in Appendix F. A graphical comparison of load vs deformation for edge distance is presented in Figure 4-8.

4.2 Tensile and Torsional Strength of Laminated Wood Bolts

Twenty bolt specimens were tested to failure in a universal testing machine. All bolt specimens had two full thickness nuts on each end. The test results are tabulated in Table 4-1.

The average tensile strength is 5193 lb with a standard deviation of 439 lb. An average change in length for 6 of the specimens is .226 in. All of the tension specimens failed by rupture at the edge of the nuts or by stripping the threads from the bolt.

Figures 4-9 and 4-10 depict examples of tension failures. It was observed during the tension testing that the nuts did not fit the bolts tightly and in several failures, it appeared that the threads failed at a point less than full depth of thread. This is shown quite clearly on specimens 17 and 19 in Figure 4-11.

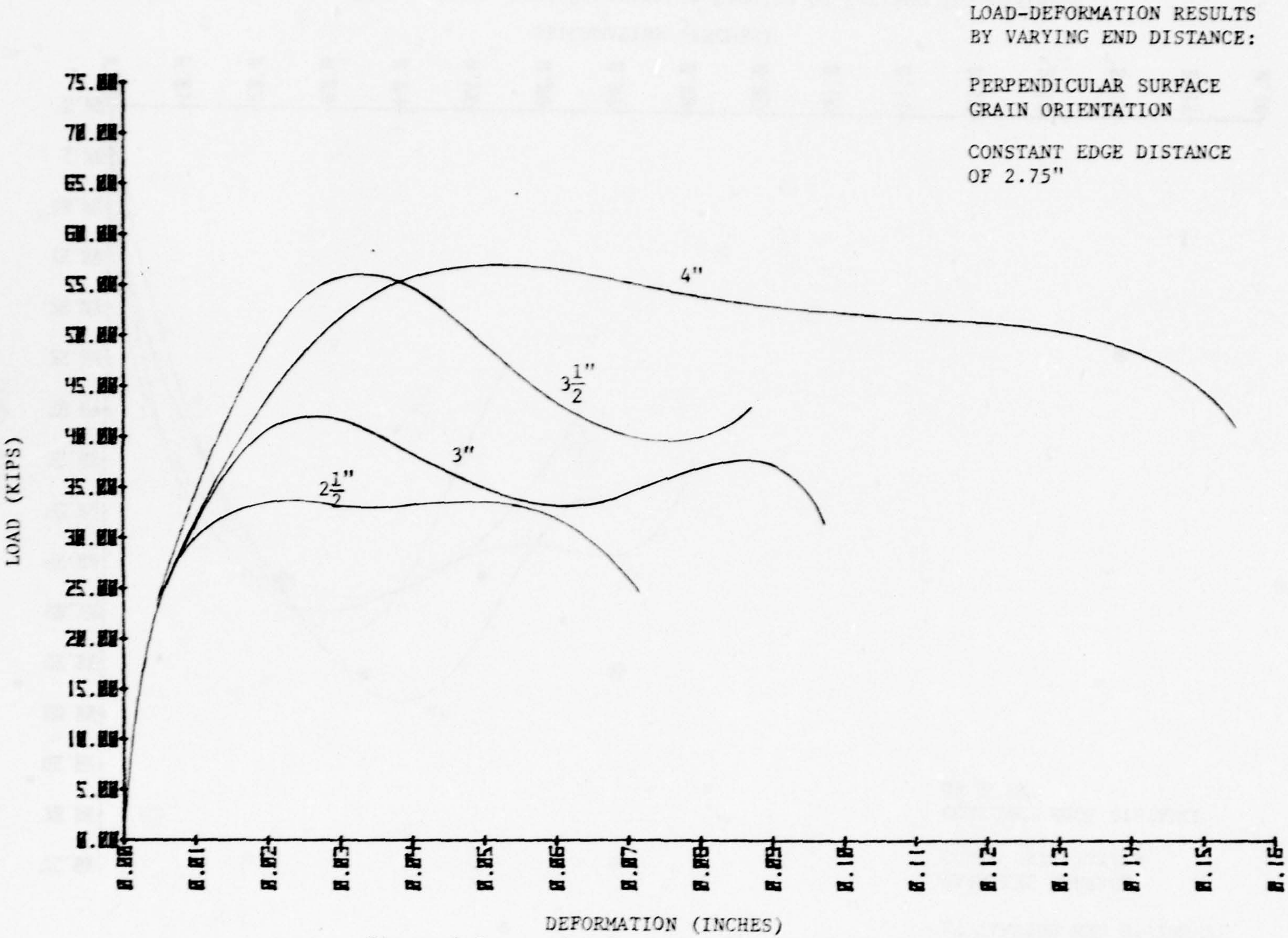


Figure 4-5: Load-Deformation Results by Varying End Distance
Perpendicular Surface Grain Orientation

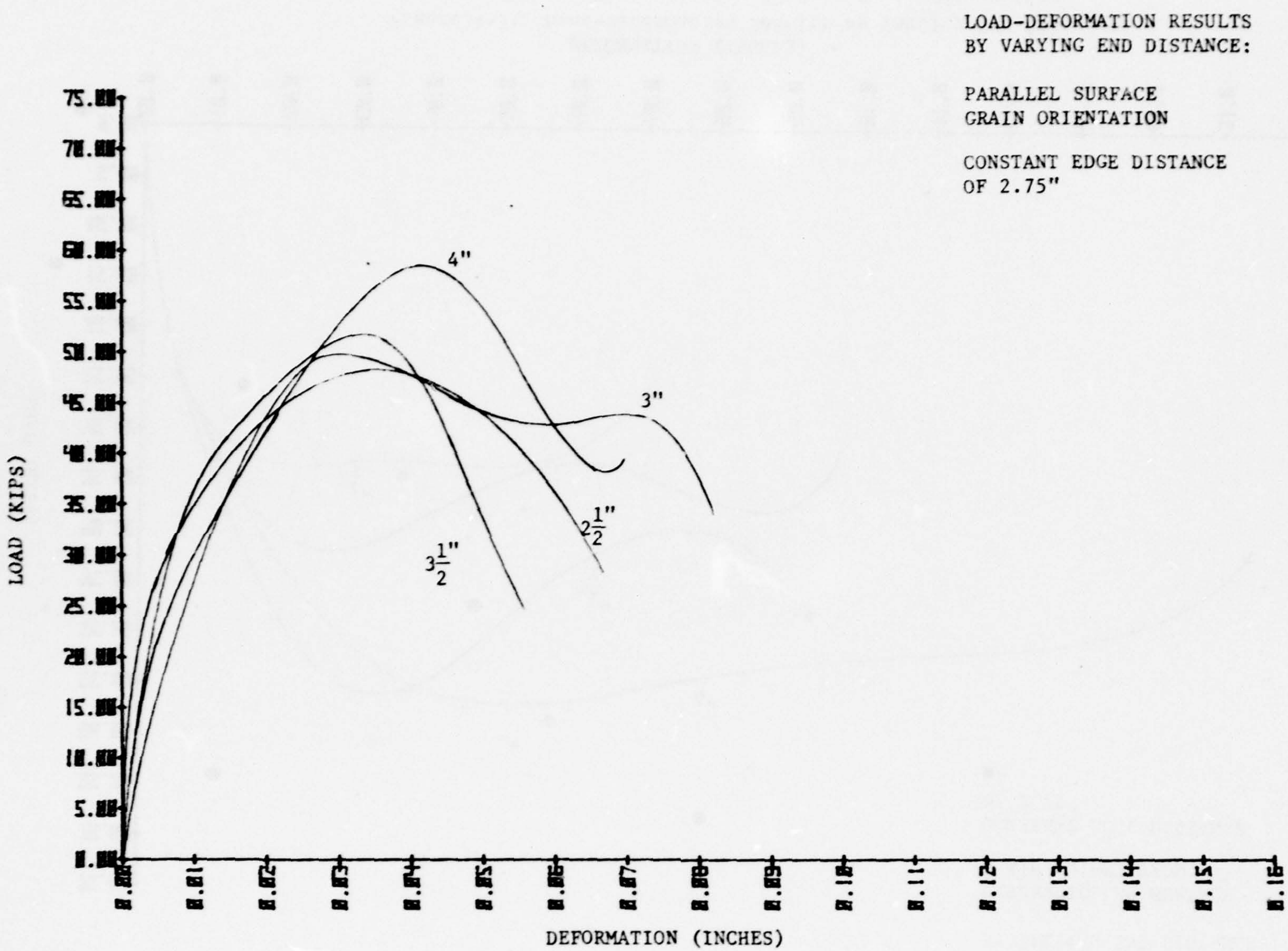


Figure 4-6: Load-Deformation Results by Varying End Distance
Parallel Surface Grain Orientation

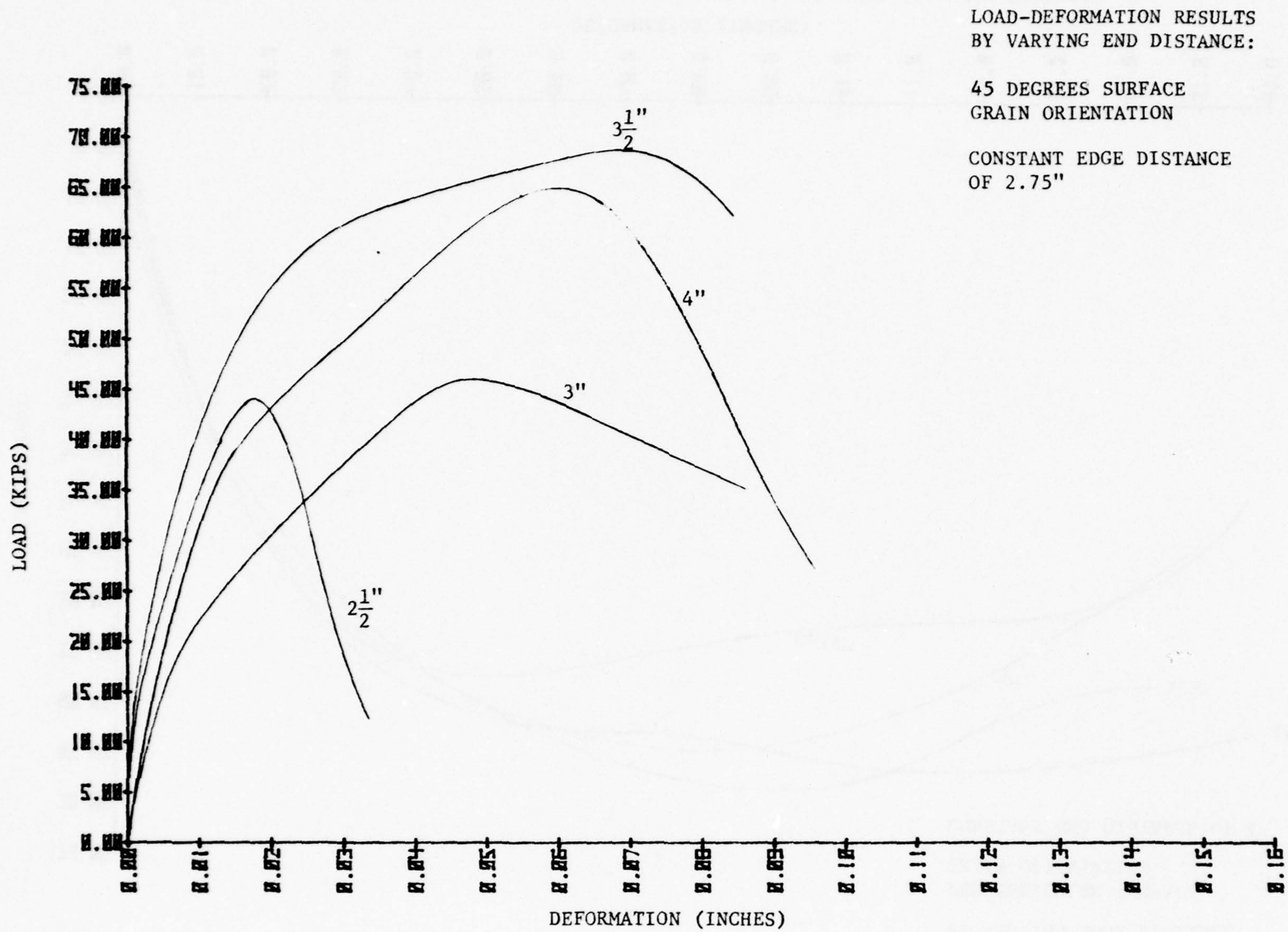


Figure 4-7: Load-Deformation Results by Varying End Distance
45 Degree Surface Grain Orientation

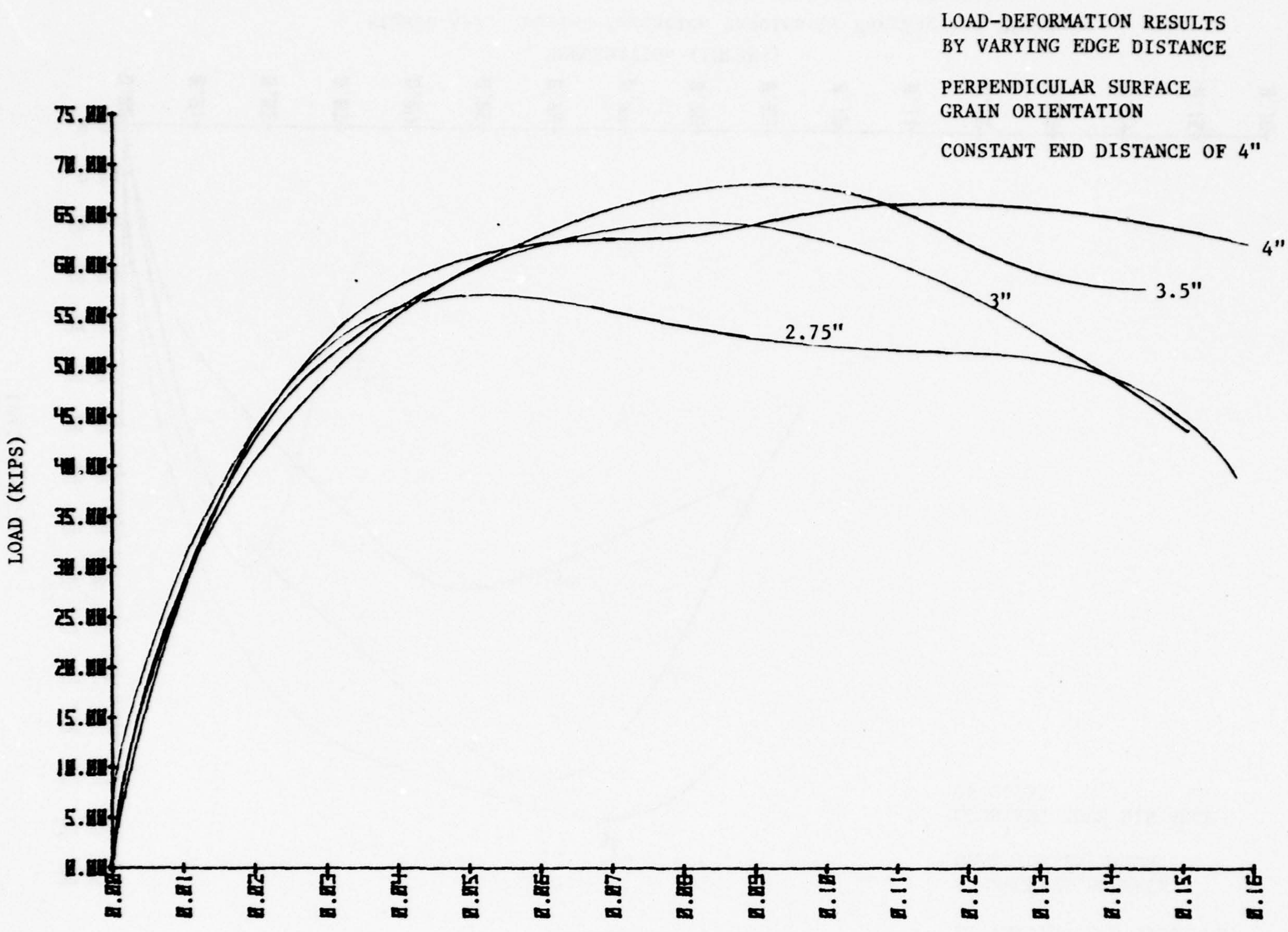


Figure 4-8: Load-Deformation Results by Varying Edge Distance
Perpendicular Surface Grain Orientation

Table 4-1 Tension Data

Tension Specimen No.	Length (in)	Ultimate Load (lb)	Change in Length (in)
1	26	5050	--
2	31	4850	--
3	31	5400	--
4	31	5950	--
5	31	6050	--
6	31	5250	--
7	31	5950	--
8	31	4850	--
9	15 1/2	5100	--
10	15 1/2	5100	--
11	15 1/2	4900	--
12	15 1/2	5125	--
13	15 1/2	5425	--
14	14	4875	--
15	31	4655	0.22
16	31	4715	0.242
17	31	4965	0.213
18	31	5820	0.235
19	31	4530	0.188
20	31	5295	0.259

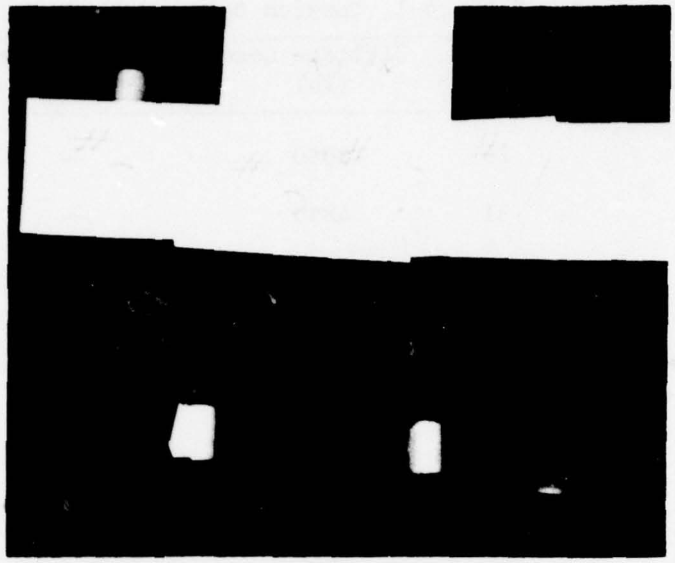


Fig 4-9: Tension Failures. Specimens 1-4

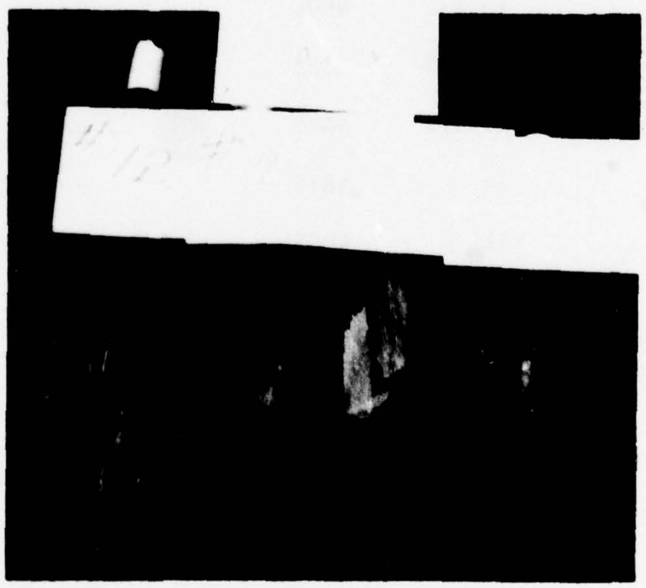


Fig 4-10: Tension Failures. Specimens 9-12

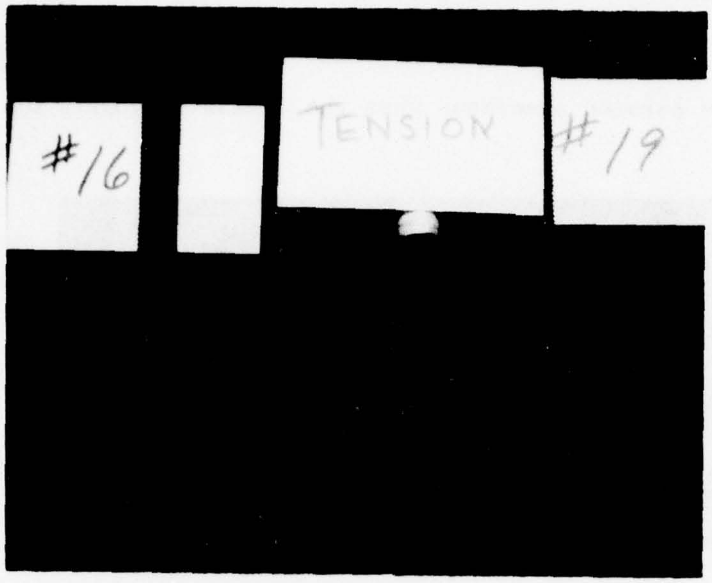


Fig 4-11: Tension Failures. Note: specimens 17 and 19 show that the threads failed at a position less than at full depth.

Ten bolts were tested in pure torsion. The results are tabulated in Table 4-2.

Table 4-2 Pure Torsion Data

Torsion Specimen No.	Ultimate Torque (ft lb)
1	27.7
2	30.5
3	27.0
4	22.4
5	39.0
6	30.5
7	26.9
8	36.0
9	22.3
10	40.8

The average torsion strength is 30.3 ft-lb and the standard deviation is 6.1 ft-lb. Figures 4-12 and 4-13 show typical torsion failures. Failures occurred in the torsion specimens when the laminated layers of wood

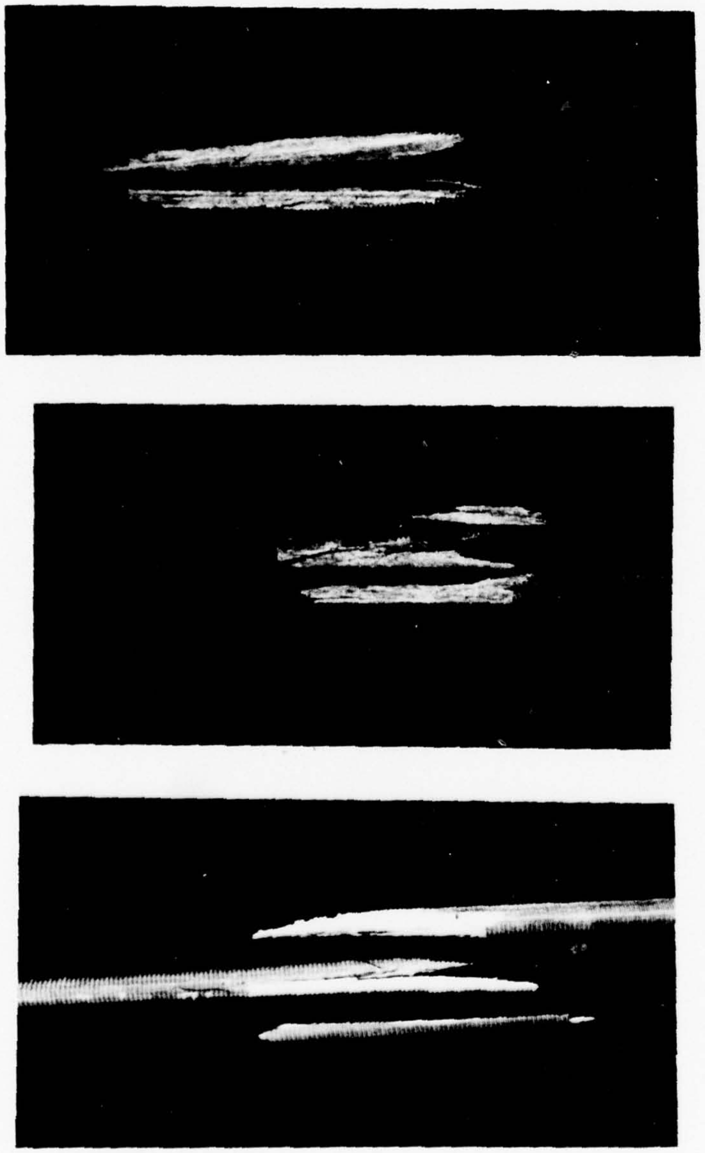


Fig 4-12: Torsion Failures. Specimens 7,8,9

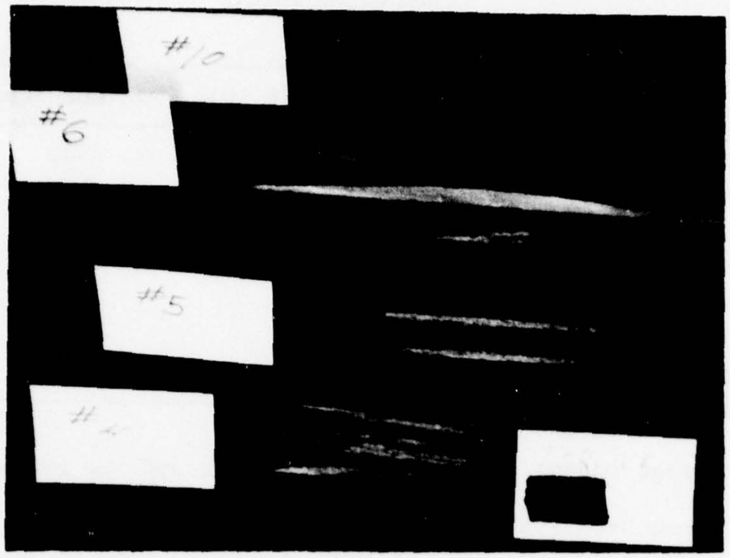


Fig 4-13: Torsion Failures. Specimens 4,5,6 and 10

separated along the laminations. Only upon continued twisting was it possible to rupture the wood fibers. In all cases, failure occurred approximately midway along the bolt. Specimen 2 was the only bolt to fail by shear failure in the threads. This was probably caused by excessive relative motion of the nuts on the bolt.

Upon completion of the testing of specimens under pure tensile and torsional loads, six bolts were tested in a manner believed to be representative of field installation. Bolt specimens were installed in the tensile testing machine and only one nut was applied to each end. These nuts were then tightened until failure occurred. At failure, the results shown in Table 4-3 were recorded.

Table 4-3 Special Test of Tension Induced by Torque

Specimen No.	Maximum Torque (ft lb)	Maximum Tension (lb)
1	34.5	2300
2	25.0	1600
3	36.6	2435
4	39.1	2460
5	43.7	2410
6	52.7	2580

The average torque applied was 38.6 ft-lb and the average tension force developed was 2298 lb. Standard deviations of 9.3 ft-lb and 353 lb were calculated.

During these tests it was observed that when the torque neared its ultimate value, sufficient friction was developed between the threads on the bolt and in the nut to cause the two to freeze. When this occurred, all torque applied to the nut went directly to overcome the unknown amount of friction between the nut and the testing machine surface and to twist the bolt. This conclusion is based on the fact that if just prior to failure the torque was released on the nut, the twist in the bolt would cause the bolt to rotate in a direction opposite to the direction of previously applied torque. It was further observed that it was necessary to apply a torque of 6 to 10 ft-lb to begin retwisting the bolt.

It can be observed in Figures 4-14 and 4-15 that the bolts failed in a manner very similar to that of pure torsion. Furthermore, all failures occurred near the middle of the full length bolts.

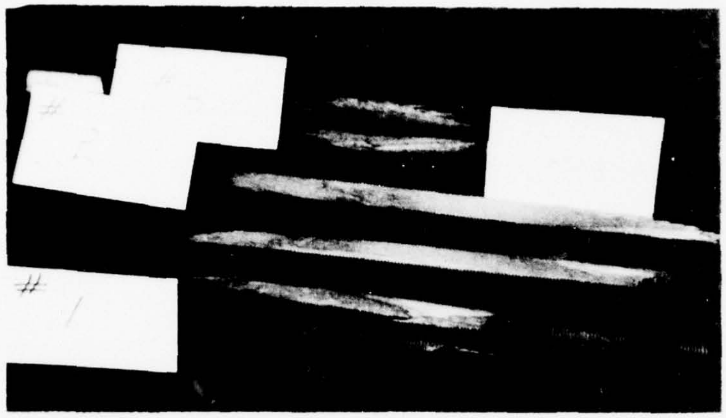


Fig 4-14: Special Tests. Tension Induced by Tightening of Bolts. Specimens 1-3

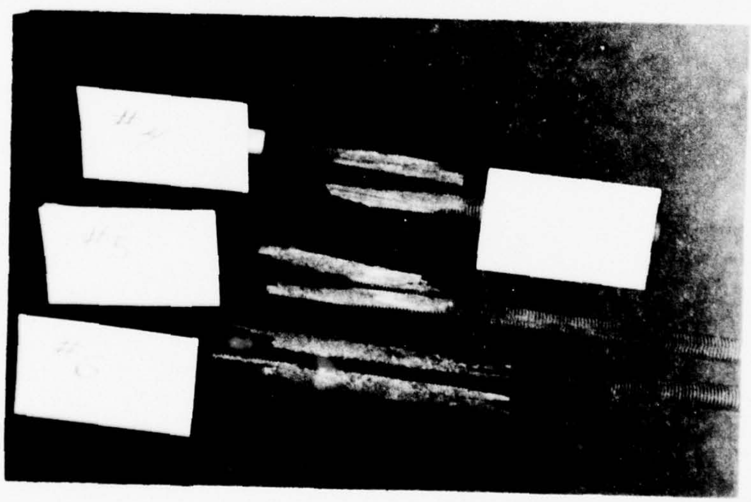


Fig 4-15: Special Tests. Tension Induced by Tightening of Bolts. Specimens 4-6

The next series of tests consisted of placing a specified level of torque on each bolt and then loading it in tension until failure

occurred. Forty nine specimens were tested to provide a reasonable quantity of data to establish the interaction diagram. In these tests it was necessary to hold the torque on the bolt until a minimum level of tension was developed in the bolt. The normal force of the loading head of the tension machine had to be sufficiently large to develop an adequate friction force between the nuts on the bolt and the loading head to prevent the bolt from untwisting and thereby reducing the applied torque. These test results are presented in Table 4-4 on the following page.

After grouping the test results corresponding to a specific level of applied torque, the results in Table 4-5 are obtained.

Table 4-5 Average Levels of Performance for Tension With Induced Torque

Applied Torque (ft lb)	P_{ult} (lb) *	Standard Deviation (lb) *	Average Change in Length (in)	Percent of Specimens Failing in Pure Torque
11.09	4902	800	.231	0
16.64	4790	719	.235	0
22.18	4902	692	.205	26.7%
27.73	4898	434	.225	66.7%

*Values are for specimens actually reaching an ultimate tensile load.

Typical examples of failure surfaces are shown in Figures 4-16, 4-17, 4-18 and 4-19 for the indicated levels of applied torque.

Table 4-4 Tension With Induced Torque

Specimen No.	Applied Torque (ft lb)	Torque Released at P =	P_{ult} (lb)	Change in Length (in)
1	11.09	1000	5410	--
2	16.64	2000	4500	--
3	22.18	2500	5334	--
4	25.51	Trying to develop T = 27.73 ft lb Failed in Pure Torque		
5	24.40	Trying to develop T = 27.73 ft lb Failed in Pure Torque		
6	19.96	Trying to develop T = 22.18 ft lb Failed in Pure Torque		
7	22.18	2500	4175	--
8	24.40	Trying to develop T = 27.73 ft lb Failed in Pure Torque		
9	22.18	2500	4145	--
10	19.96	Trying to develop T = 22.18 ft lb Failed in Pure Torque		
11	22.18	2500	4090	--
12	Test machine malfunctioned - data lost			
13	11.09	1500	5350	--
14	11.09	1500	5080	--
15	11.09	1500	5355	--
16	11.09	1500	4190	--
17	11.09	1500	3910	0.22
18	11.09	1500	5750	0.242
19	11.09	1500	3350	0.224
20	16.64	1500	6190	0.262
21	16.64	1500	3840	0.19
22	16.64	1500	3980	0.197
23	16.64	1500	5795	0.234
24	16.64	1500	4515	0.234
25	16.64	1500	4740	0.240

Table 4-4 Tension With Induced Torque (Cont'd)

Specimen No.	Applied Torque (ft lb)	Torque Released at P =	P_{ult} (lb)	Change in Length (in)
26	16.64	1500	4670	0.230
27	16.64	1500	5310	0.244
28	16.64	1500	4355	0.287
29	11.09	1500	4695	0.215
30	11.09	1500	5925	0.255
31	18.30	Trying to develop T = 22.18 ft lb Failed in Pure Torque		
32	22.18	2000	4185	0.192
33	22.18	2000	5860	0.251
34	27.17	Trying to develop T = 27.73 ft lb Failed in Pure Torque		
35	22.18	2000	5600	0.223
36	22.18	2500	4315	--
37	22.18	4000	5825	0.192
38	21.07	Trying to develop T = 22.18 ft lb Failed in Pure Torque		
39	22.18	4000	5305	0.191
40	22.18	4000	5090	0.18
41	22.74	Trying to develop T = 27.73 ft lb Failed in Pure Torque		
42	27.73	4000	4795	0.235
43	17.19	Trying to develop T = 27.73 ft lb Failed in Pure Torque		
44	27.73	4000	5520	0.253
45	27.73	Failed in Pure Torque		
46	28.28	Trying to develop T = 30 ft lb Failed in Pure Torque		
47	27.73	4000	4510	--
48	26.62	Trying to develop T = 27.73 ft lb Failed in Pure Torque		
49	27.73	4000	4765	0.187

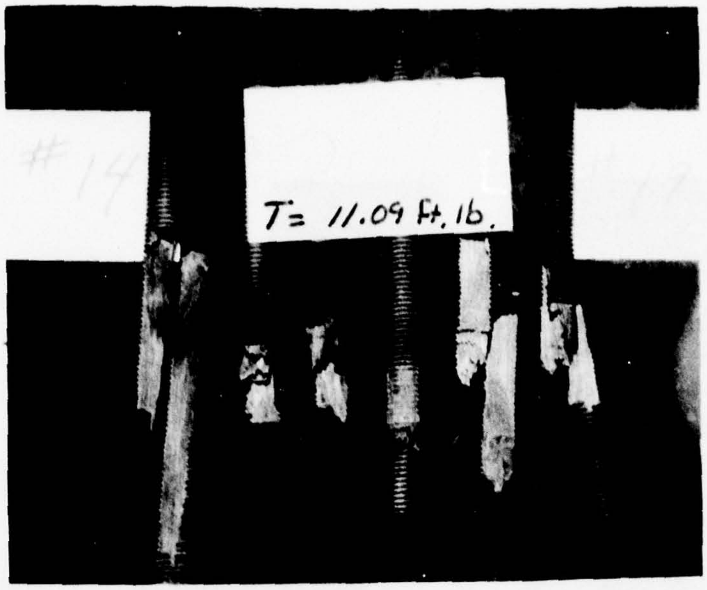


Fig 4-16: Tension Failure of Specimens
With Initial Torque of 11.09 ft-lb

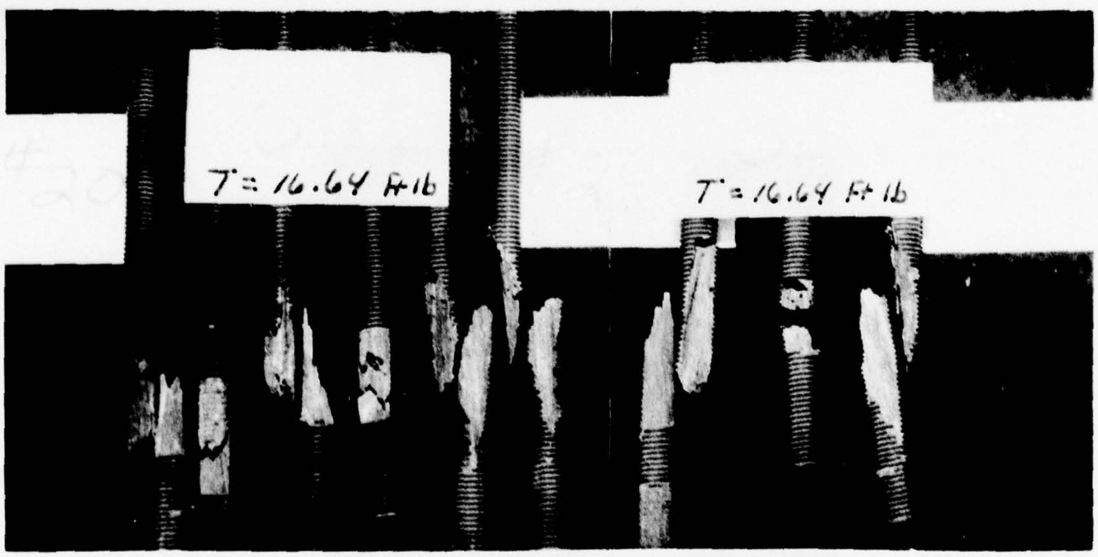


Fig 4-17: Tension Failure of Specimens
With Initial Torque of 16.64 ft-lb

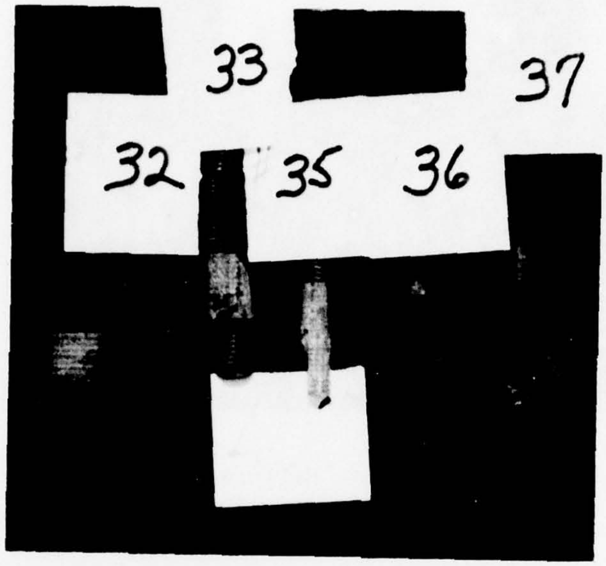


Fig 4-18: Tension Failure of Specimens
With Initial Torque of 22.18 ft-lb

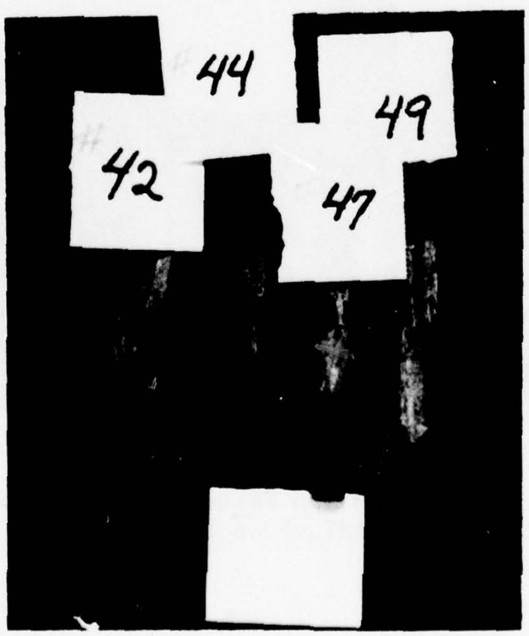


Fig 4-19: Tension Failure of Specimens
With Initial Torque of 27.73 ft-lb

4.3 Moisture Absorption of Laminated Wood Bolts and Nuts

Twenty six bolts were selected at random for moisture absorption and strength testing. Sixteen bolts and ten full and half nuts were placed in water for varying lengths of time prior to testing. The remaining ten bolts and nuts were placed in a moist room (approximate 100% relative humidity) for approximately 30 days. The bolts and nuts in the moist room were weighed regularly to determine the quantity of water absorbed. On the 28th day, five bolt specimens were tested in tension and five bolt specimens were tested in torsion. The nuts were permitted to air dry to determine if cracking and delamination would occur. The nuts could not be fitted to the bolts as they had absorbed sufficient water and swelled, reducing the inside diameter of the threads. Tables 4-6 through 4-10 present the test data.

Table 4-6 Moisture Absorption by Full Length Bolts

Specimen No.	Dry Weight (grams)	Weight Gain (grams)							
		1Day	2Days	5Days	8Days	12Days	16Days	20Days	28Days
1	243.1	2.8	3.7	5.5	7.0	8.6	10.4	11.1	12.3
2	238.1	2.8	3.8	5.7	6.8	8.8	10.7	11.6	13.2
3	238.9	2.0	3.2	5.1	6.2	7.8	9.2	10.0	11.9
4	237.1	1.9	3.5	5.4	6.7	8.6	9.7	10.7	12.9
5	239.4	1.7	2.8	4.7	6.1	7.7	8.9	9.8	11.4
6	234.0	1.9	3.3	4.9	6.4	7.9	9.6	10.6	12.4
7	236.4	2.1	3.2	5.0	6.3	8.0	9.5	10.2	12.5
8	230.0	3.0	4.3	6.1	8.2	10.0	12.0	12.4	18.5
9	235.2	2.4	4.0	6.0	7.5	9.0	10.9	11.1	12.9
10	237.2	2.6	3.8	6.2	7.6	9.7	11.2	12.1	14.3
Avg Weight Gain	236.9	2.3	3.6	5.5	6.9	8.6	10.2	11.0	13.2

Table 4-7 Moisture Absorption by Full Nuts

Specimen No.	Dry Weight (grams)	Weight Gain (grams)							
		1Day	2Days	5Days	8Days	12Days	16Days	20Days	33Days
1	28.55	.27	.33	.54	.8	1.14	1.44	1.62	2.63
2	29.35	.20	.28	.45	.64	.73	.84	1.04	1.68
3	28.29	.21	.26	.46	.65	.84	.96	1.18	1.79
4	28.62	.18	.24	.37	.49	.68	.75	.88	1.37
5	29.08	.19	.25	.55	.85	1.00	.94	1.35	2.31
6	29.66	.17	.21	.34	.49	.64	.70	.78	1.33
7	26.95	.21	.37	.71	1.06	1.58	1.75	2.03	3.04
8	29.22	.17	.27	.48	.67	.91	.99	1.21	2.10
9	29.24	.18	.32	.50	.69	.88	1.06	1.15	1.93
10	28.01	.17	.28	.64	.89	1.03	1.18	1.37	2.20
Avg Weight Gain	28.70	.20	.28	.50	.72	.94	1.06	1.26	2.04

Table 4-8 Moisture Absorption by Half Nuts

Specimen No.	Dry Weight (grams)	Weight Gain (grams)							
		1Day	2Days	5Days	8Days	12Days	16Days	20Days	33Days
1	14.75	.27	.42	.78	1.12	1.52	1.72	1.91	2.25
2	15.96	.09	.17	.34	.53	.75	.85	1.02	1.47
3	16.23	.13	.19	.32	.45	.61	.70	.80	1.37
4	16.20	.10	.21	.35	.49	.71	.78	.96	1.45
5	15.71	.14	.19	.36	.47	.63	.70	.83	1.32
6	15.60	.14	.21	.34	.44	.63	.69	.78	1.12
7	16.43	.15	.23	.38	.50	.69	.77	1.09	1.81
8	15.85	.14	.25	.40	.58	.80	.88	1.02	1.44
9	16.10	.13	.21	.38	.53	.79	.88	1.00	1.52
10	15.68	.16	.25	.34	.54	.77	.86	1.03	1.60
Avg Weight Gain	15.85	.15	.23	.40	.57	.79	.88	1.04	1.54

Table 4-9 Tensile Strength After Prolonged Exposure to Moisture

Specimen No.	Days Exposed to Moisture: 100% Humidity	Days Exposed to Moisture: Water Tank	P_{ult} (lb)	Change in Length (in)
11		3	5590	0.25
12		3	6500	0.38
13		3	6260	0.36
14		7	5730	0.31
15		7	5500	0.25
16		7	6310	0.29
3		15	4350	--
5		15	3800	--
7		15	Broke in torsion while placing nuts	
9		15	4200	--
10		15	3900	--
1	28		5890	.254
2	28		4750	.248
4	28		6320	.305
5	28		6700	.268
7	28		5960	.310
Average Values		3	6117	.33
		7	5847	.28
		15	4063	--
	28		5924	.28

Table 4-10 Torsion Strength After Prolonged Exposure to Moisture

Specimen No.	Days Exposed to Moisture: 100% Humidity	Days Exposed to Moisture: Water Tank	T_{ult} (ft lb)
1		16	20.5
2		16	30.5
4		16	37.2
6		16	30.5
8		16	26.6
5	28		20.5
6	28		20.5
8	28		18.3
9	28		26.6
10	28		18.6
Average Values		16	29.1
	28		20.9

CHAPTER 5

DISCUSSION

5.1 Shear Strength of Split-Rings in Laminated Wood Gusset Plates

The end distance, or distance between the center of the bolt hole and the end of the outer plate, had a considerable and well-defined influence on the behavior of the joint. An evaluation of the magnitude of this influence can best be made using Figure 4-5, which is the "Load-Deformation Results by Varying End Distance" graph for the perpendicular surface grain orientation. Recall that five specimens were tested to determine each of the four curves depicted in this figure.

The curves in Figure 4-5 illustrate the central tendency of behavior between load and deformation for varying end distances and do not reflect the test behavior of an individual specimen. Typically, an individual specimen, as can be seen in the individual data curves of Appendix C, exhibited a saw-toothed pattern of load reduction with increasing deformation. A loud cracking sound was observed as most test specimens reached ultimate load, followed by a load reduction with increasing deformation. Several tests were terminated after the loud cracking sound and it was found that only the core area within the split-ring had failed. Hence it is estimated that the ultimate strength coincides with the failure of this core area. Occasionally, a load drop accompanied a minor failure before the ultimate load was reached, and a small cracking sound was noticeable when this happened.

The curves in Figure 4-5 are not intended to illustrate behavior past ultimate, since this region is of little practical value. They merely substantiate that there is no effective load gain past ultimate. There is relative unpredictability in the load-reduction pattern past ultimate.

None of the curves, individual or consolidated, exhibit a well-defined proportional limit. This is understandable considering the non-linear nature of the laminated wood material. As anticipated, the ultimate load increased as the end distances increased. Since the ultimate loads for the 3.5 inch and 4 inch end distance specimens were approximately the same, a constant ultimate load is suggested past an end distance of 3.5 inches. The curves of Figure 4-5 also exhibit approximately the same initial load-deformation relationship up to about 25 Kips.

After evaluating the consolidated curves of Figures 4-6 and 4-7 up to the ultimate value of load, it becomes apparent that there is little difference in the load-deformation relationship for the perpendicular, parallel, or 45-degree orientations to the direction of loading for a given end distance. This is as anticipated, due to the cross-lamination of the PERMALI plates. As previously noted, little can be predicted past the ultimate value.

The failed surfaces of each of the two core areas revealed that 85% of the failure planes occurred in the outer plate at a depth of 0.15 to 0.35 inches measured from the inside face of the outer plates, or at about half the seating depth of the split-ring connector.

Approximately 10% of the failure planes occurred between 0.35 to 0.50 inches, or closer to the full seating depth of the rings in the outer plates. Almost 5% of the failure planes occurred within the driver block core area, Figure 3-1.

Regarding the appearance of the sheared core areas, over 73% of the failure planes occurred cleanly between the laminations without obvious splintering of the beech layer. Of the 27% which sheared across laminations, 23% sheared across one lamination, and 4% across two laminations. There was no noticeable correlation between the ultimate load and the location or appearance of the sheared core areas. Thus, the failure planes seemed to occur along the weakest lamination interface near mid-seating depth of the split-ring connector in the outer plates.

As mentioned earlier, the wood used to manufacture the PERMALI plates was highly densified and impregnated with resins. This obviously increased the stiffness characteristics of the wood and also caused it to behave as a brittle material. As a result, it was meaningless to carry the laboratory tests beyond 0.15 inches of deflection although the ASTM requires 0.60 inches of deflection.

Failure of bolts warrant little mention since they could only be failed long after ultimate load value was reached and after the area beneath the core area had sheared. Had the bolts been torqued past "hand-tight" or "snug", a different result might have occurred from bulging (or spreading) of the specimens at the connectors after reaching

ultimate strength. There was no noticeable bulging of the specimens at the connectors before ultimate.

It should be pointed out that the ultimate load carried by each test specimen was in reality supported by two split-rings. Therefore, the capacity of one split-ring connector is one half of that shown on the data plots. In addition, this ultimate load must be reduced by the conventional capacity reduction factor of 1.65 to correct for the effects of load duration in wood. These values are shown in Table 5-1.

Table 5-1

Average Ultimate Load

End Distance	Orientation of Load to Face Grain	Ultimate Load (Uncorrected)
2 1/2"	90^o	18 kips/ring
3"	90^o	24
3 1/2"	90^o	30
4"	90^o	31
2 1/2"	0^o	25
3"	0^o	27
3 1/2"	0^o	26
4"	0^o	31
2 1/2"	45^o	22
3"	45^o	25
3 1/2"	45^o	32
4"	45^o	33

Edge distance, or the distance between the center of the bolt and the edge of the outer plates, had an influence on the behavior of the joint similar to that experienced during tests using end distance as

the variable under study. As anticipated, the ultimate load increased as the edge distances increased. Since the ultimate loads for the 3.5 inch and 4 inch edge distance specimens were approximately the same, a constant ultimate load is suggested past a 3.5 inch edge distance for a given end distance of 4 inches. The curves of Figure 4-8 also exhibit approximately the same initial load-deformation relationship up to about 55 Kips.

The failures which accompanied the ultimate load for all edge distances tested was essentially the same experienced in the test specimens with variable end distances. The failed surface of each of the two core areas revealed that 85% of the failure planes occurred in the outer plates at a depth of 0.15 to 0.30 inches measured from the inside face of the outer plates, or at about half the seating depth of the split-ring connector. Approximately 8% of the failure planes occurred between 0.30 and 0.50 inches, or closer to the full seating depth of the rings in the outer plates. Almost 7% of the failure planes occurred within the driver block core area.

Approximately 50% of the failure planes occurred cleanly between the laminations of the sheared core area without significant splintering of the wood layers. Of the 50% which sheared across laminations, 30% sheared across one lamination, and 20% across two or more laminations. There was no noticeable correlation between the ultimate load and the location or appearance of the sheared core areas. Similar to the tests with variable end distances, the failure planes seemed

to occur along the weakest lamination interface near mid-seating depth of the split-ring connector in the outer plates.

In the series of tests having variable edge distances and a constant end distance of 4 inches, almost all of the bolts failed. A best estimate as to when failure occurred would be after ultimate load had been reached and during the long period of relatively constant load capacity. It was during this later period of loading that the specimens showed visible signs of bulging (Figure 5-1).

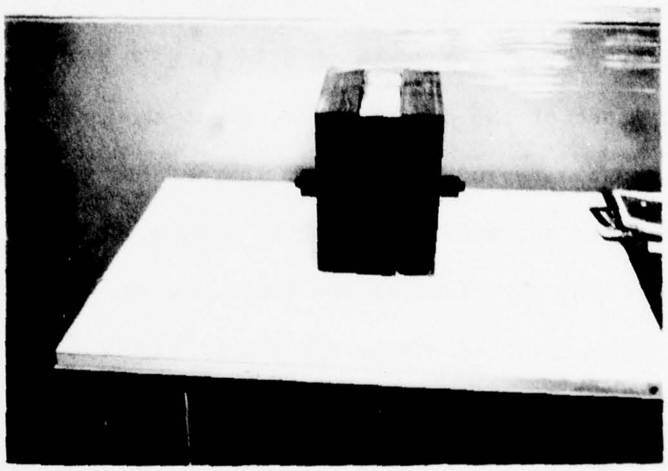


Fig 5-1: Bulging of
Test Specimen
(Note separation between plates)

The ultimate capacity of one split-ring connector is one half of that shown on the data plots. This ultimate load for one split-ring as shown in Table 5-2 must be reduced by the conventional capacity reduction factor of 1.65 to correct for the effects of load duration and arrive at an allowable maximum long term capacity.

Table 5-2

Average Ultimate Load for Specimens
With Variable Edge Distance
(4 inch end distance)

Edge Distance	Orientation of Load to Face Grain	Ultimate Load (Uncorrected
2.75	90^{o}	31 kips/ring
3.00	90^{o}	33.5
3.50	90^{o}	35.7
4.00	90^{o}	34.4

5.2 Strength of Laminated Wood Bolts

Laboratory testing for material properties frequently produces results with considerable scatter in the data. This is particularly true when testing non-homogeneous materials. Such was the case with the tests to establish the tension-torsion interaction diagram for phenolic resin impregnated laminated beech wood bolts. Figure 5-2 shows the test results for 79 wood bolts tested under various combinations of tensile and torsional stresses. As shown in Figures 4-9, 4-10, and 4-11, many of the tension specimens failed by shearing of the threads. This was a continuous problem throughout the test program and was the primary reason why the bolts were extended through

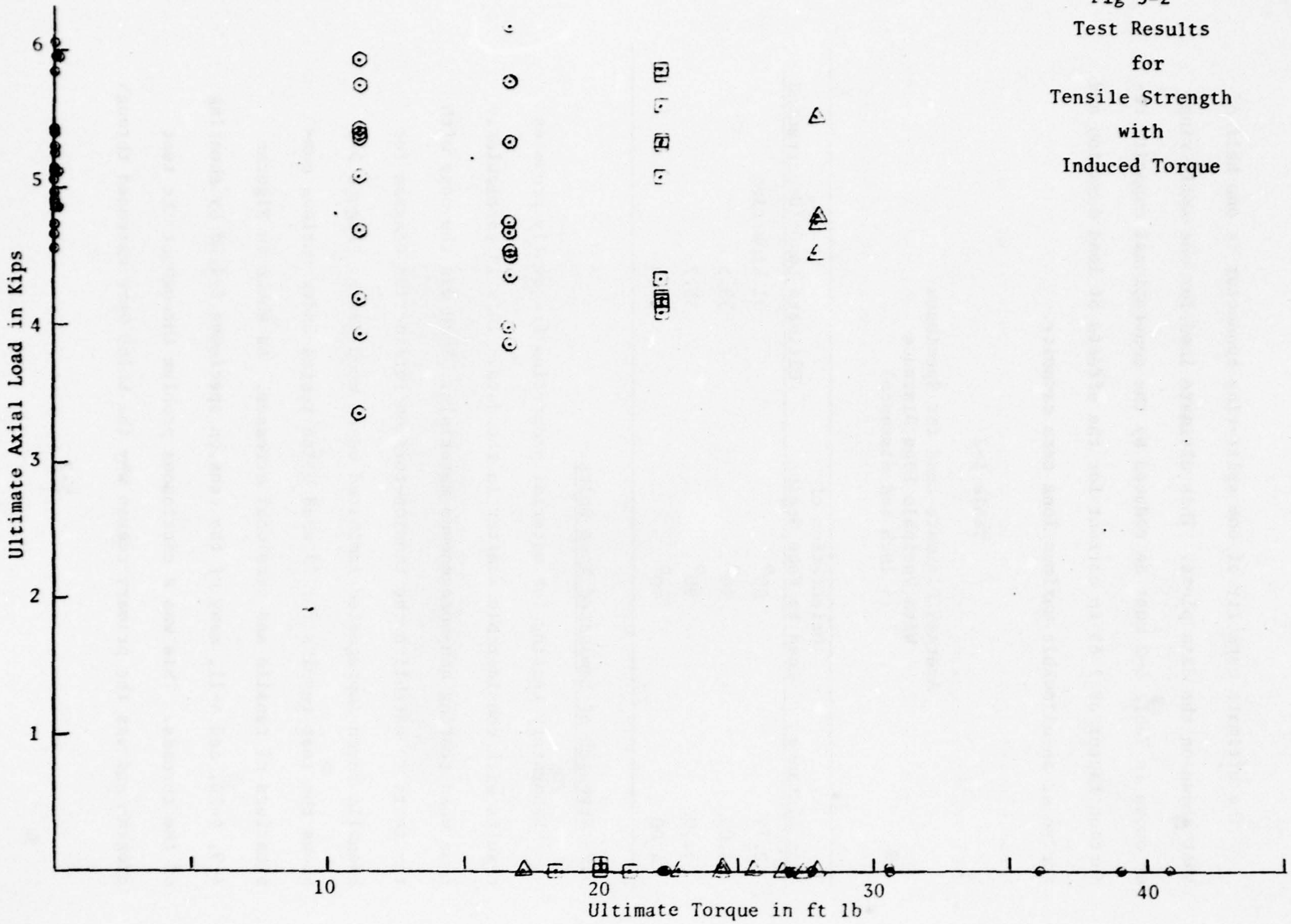


Fig 5-2
Test Results
for
Tensile Strength
with
Induced Torque

the heads of the testing machine with two full size nuts attached to each end of the bolt. The standard length test specimen holders were too short to develop even a reasonable strength in the bolt.

Average values and standard deviations for the ultimate tensile strength developed in the bolts under specified levels of applied torque are tabulated in Table 4-5. These values are based on test data for only those specimens developing tensile stresses after the specified torque had been applied. This, in the opinion of the writer, is not totally realistic as a large percentage of the bolts failed in pure torque as the specified level of torque approached the average ultimate torque under pure torsional stresses. When all of the specimens selected for any level of combined tension and torque are used, some of the average tensile values are significantly reduced as shown in Table 5-3 and Figure 5-3.

Table 5-3

Average Levels of Performance for Tension With Induced Torque (All Specimens Included in Computation of Average Values)

Applied Torque (ft lb)	P_{ult} (lb)	Standard Deviation (lb)	Avg Change in Length (in)	Percent of Specimens Failing in Pure Torque
11.09	4902	800	.231	0
16.64	4790	719	.235	0
22.18	3595	2247	.205	26.7%
27.73	1633	2319	.225	66.7%

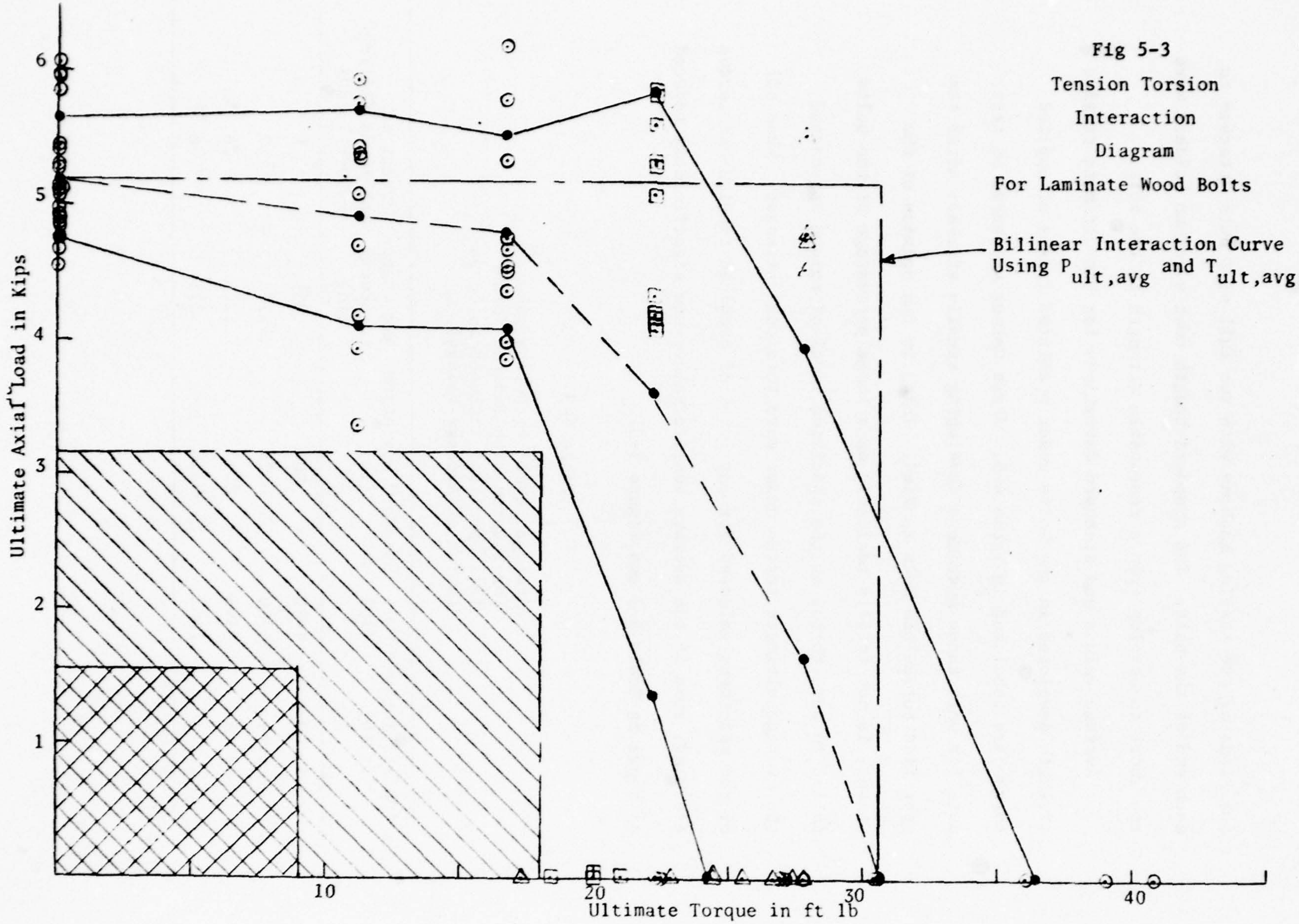


Fig 5-3
Tension Torsion
Interaction
Diagram
For Laminate Wood Bolts

The plot of these average values in Figure 5-3 could serve as a possible interaction diagram. However, if one looks further into the data and realizes that at high levels of applied torque only 33% of the bolts were sufficiently strong to develop the torque and then sustain tensile stresses, it would seem equally valid to consider the material to be bilinear. This bilinear curve is based on average ultimate loads in pure tension and pure torsion. Reducing these values for a load duration factor of 1.65, the bilinear interaction curve then encloses the area with the single diagonal lines on Figure 5-3. If now a factor of safety of 2 is used, the allowable interaction curve encloses the area on Figure 5-3 with the cross diagonal lines.

Although the bolts were impregnated with resins, the moisture absorption tests showed that the nuts and bolts would absorb approximately 6 percent of their weight in water if exposed to a high humidity environment. These results are shown in Figures 5-4 and 5-5. It is generally agreed that when resins absorb moisture, their properties change.

Testing of the specimens which had been exposed to moisture revealed an initial gain in tensile strength followed by a loss in strength, Figure 5-6. Furthermore, different levels of strength loss were experienced for those specimens exposed to a high humidity environment and a water bath. The initial increase in tensile strength can probably be attributed to the swelling of the bolts thereby providing a tighter fit between the nuts and bolts. Most of the threads which failed during the testing of these bolts appeared to have sheared off at a plane closer to the core of the bolt. Standard wood fibers which have been

Fig 5-4
Average
Moisture Absorption
for
Full Length Wood Bolts

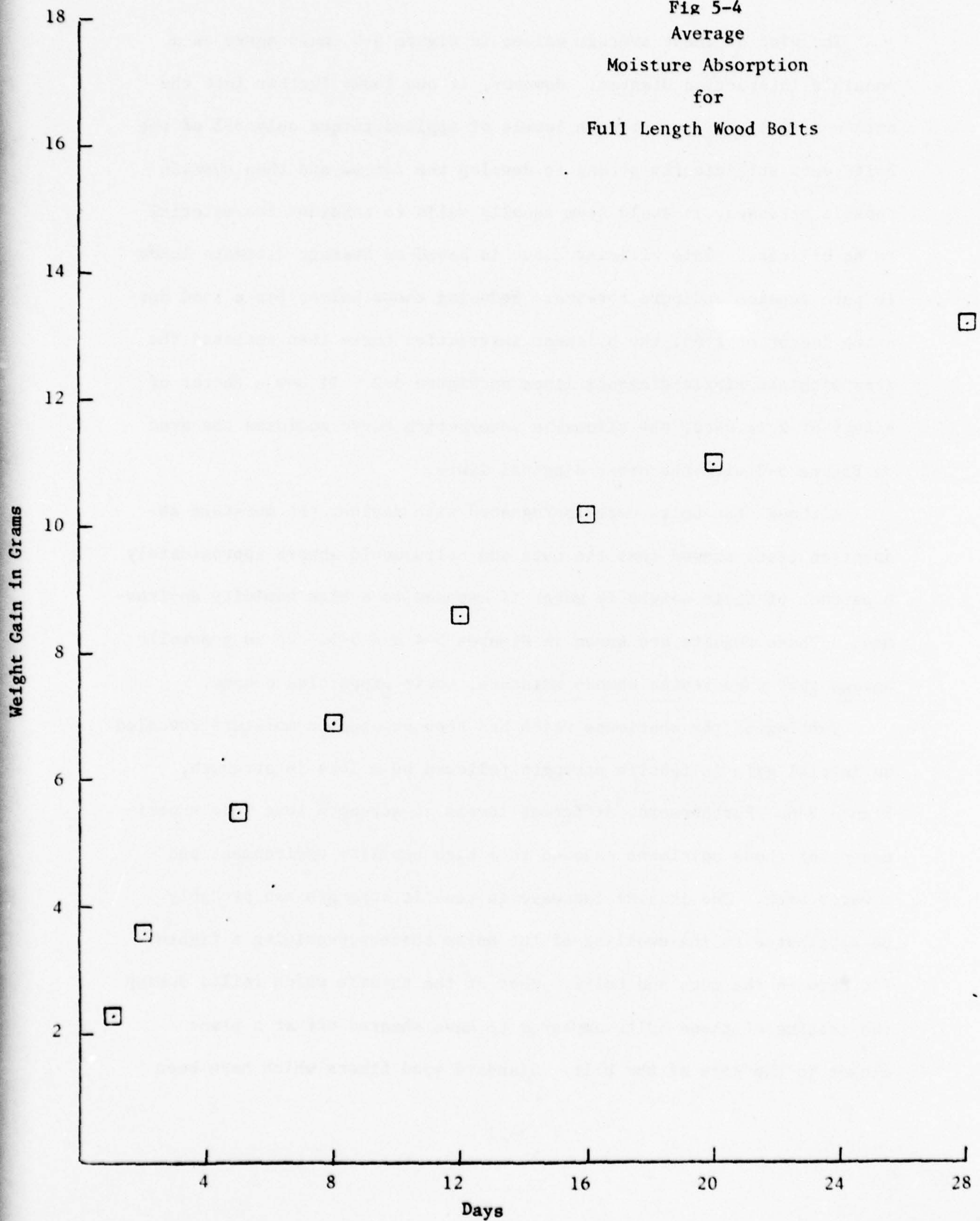


Fig 5-5
Average
Moisture Absorption
for
Wood Nuts

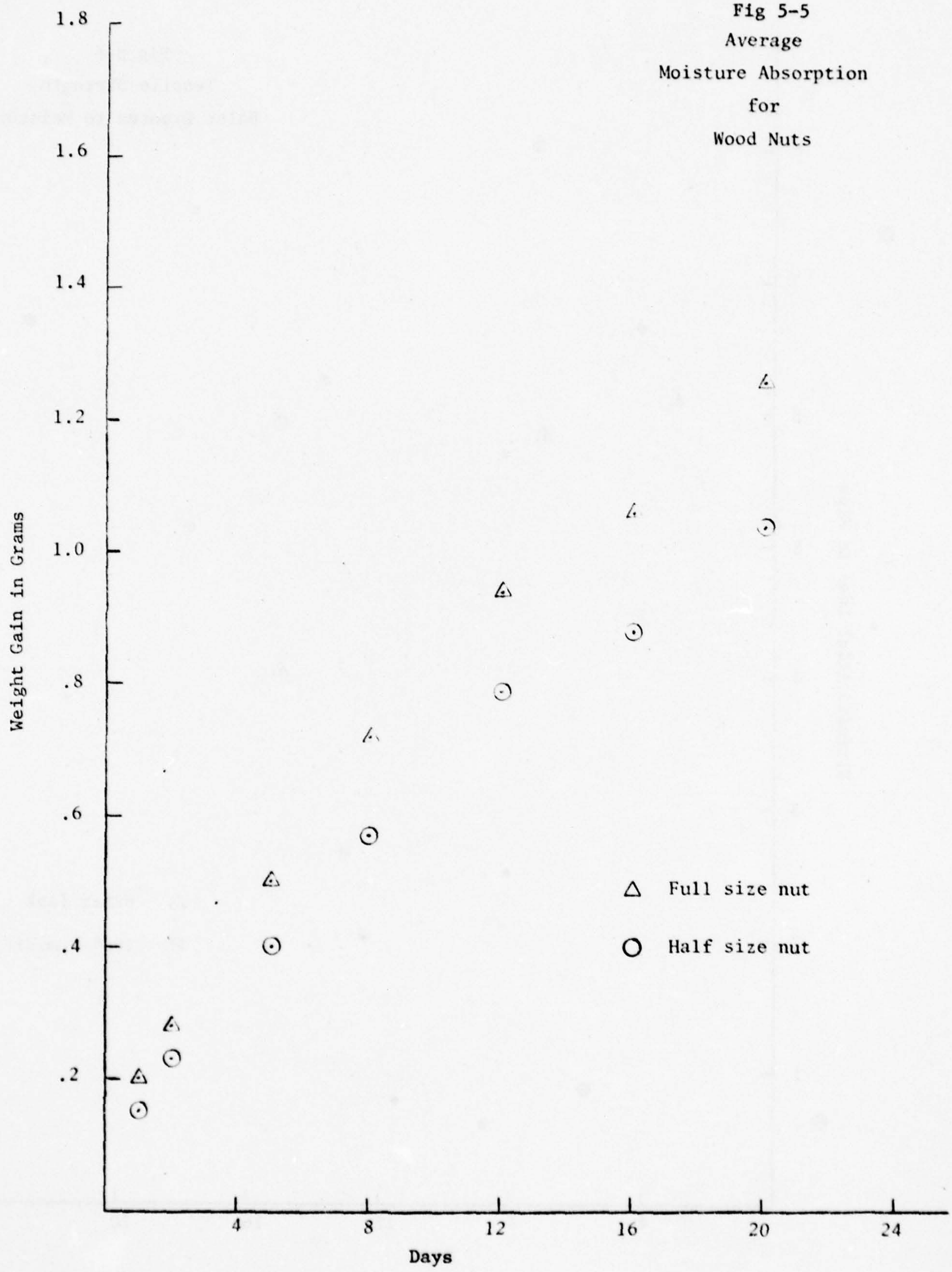
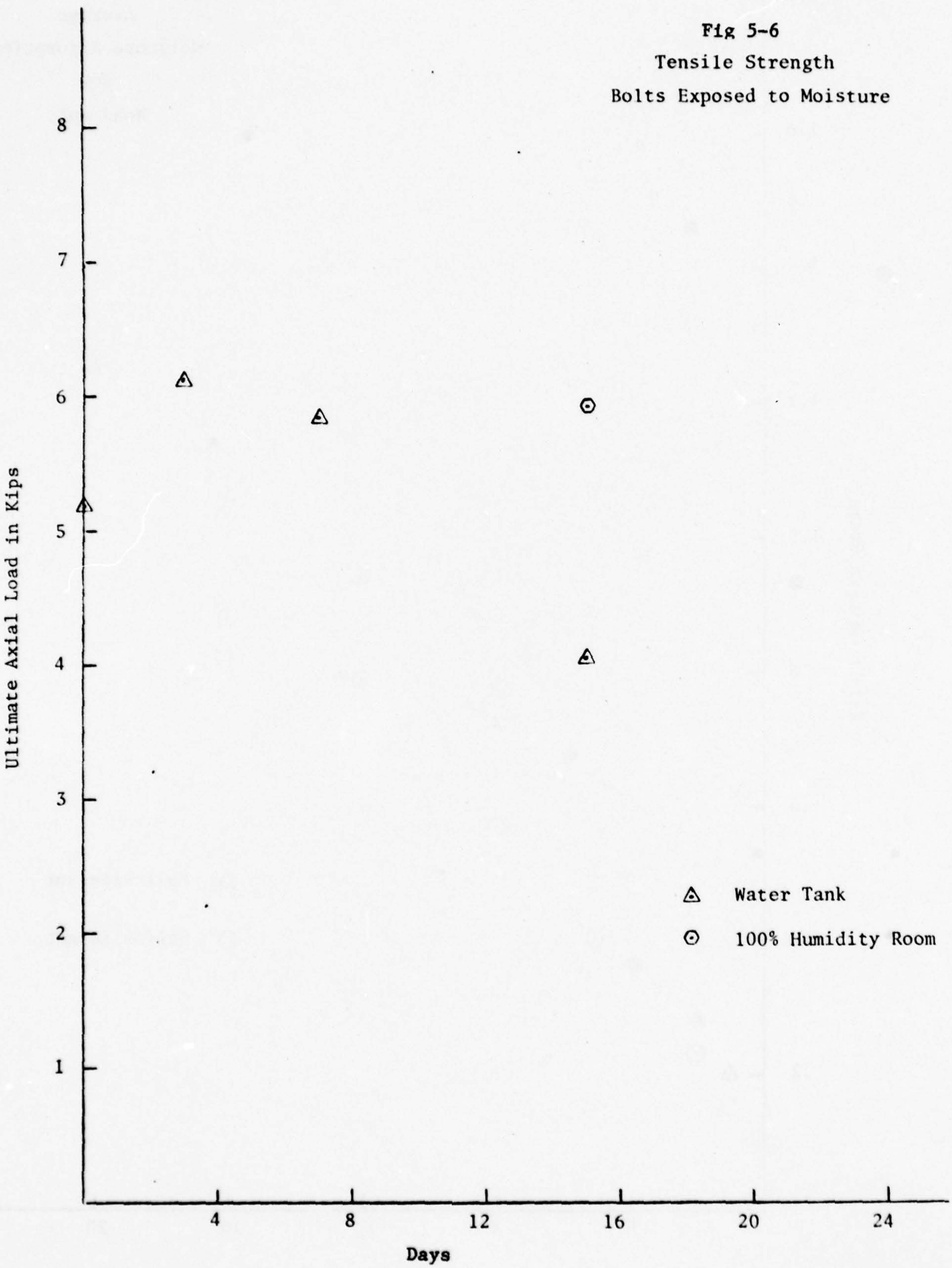


Fig 5-6

Tensile Strength

Bolts Exposed to Moisture



exposed to mositure for prolonged periods of time will absorb water and hence develop lower levels of ultimate strength. Such would appear to be the case for the specimens placed in the water bath. Apparently, the wood fibers absorb less moisture in a high humidity environment than in a water tank and consequently do not lose as significant a portion of their ultimate strength.

In a similar manner, the bolts which had been exposed to moisture developed reduced levels of strength when tested in pure torsion, Figure 5-7. In this case it is not clear as to the effect of moisture absorbed in a high humidity room as opposed to a water bath. There is information available on testing of composite materials at the Air Force Materials Laboratory which would support the premise that a high humidity environment is more detrimental on a phenolic resin than is a water bath. Since the torsion test specifically subjects the phenolic matrix to high levels of stress, this could account for the 30 percent loss in torsional strength after 28 days in a moist environment.

The last series of tests which deserve some comment is the special test which simulated field installation. In these tests, the bolts failed in a manner similar to failure under pure torque. At the time of failure the bolts had developed approximately 45 percent (2295 lb) of their ultimate tensile strength. Although the bolts had sufficient residual tensile strength, improper tightening of the nuts or tightening to a level which tends to freeze the nut and bolt could easily fail the bolts in torque.

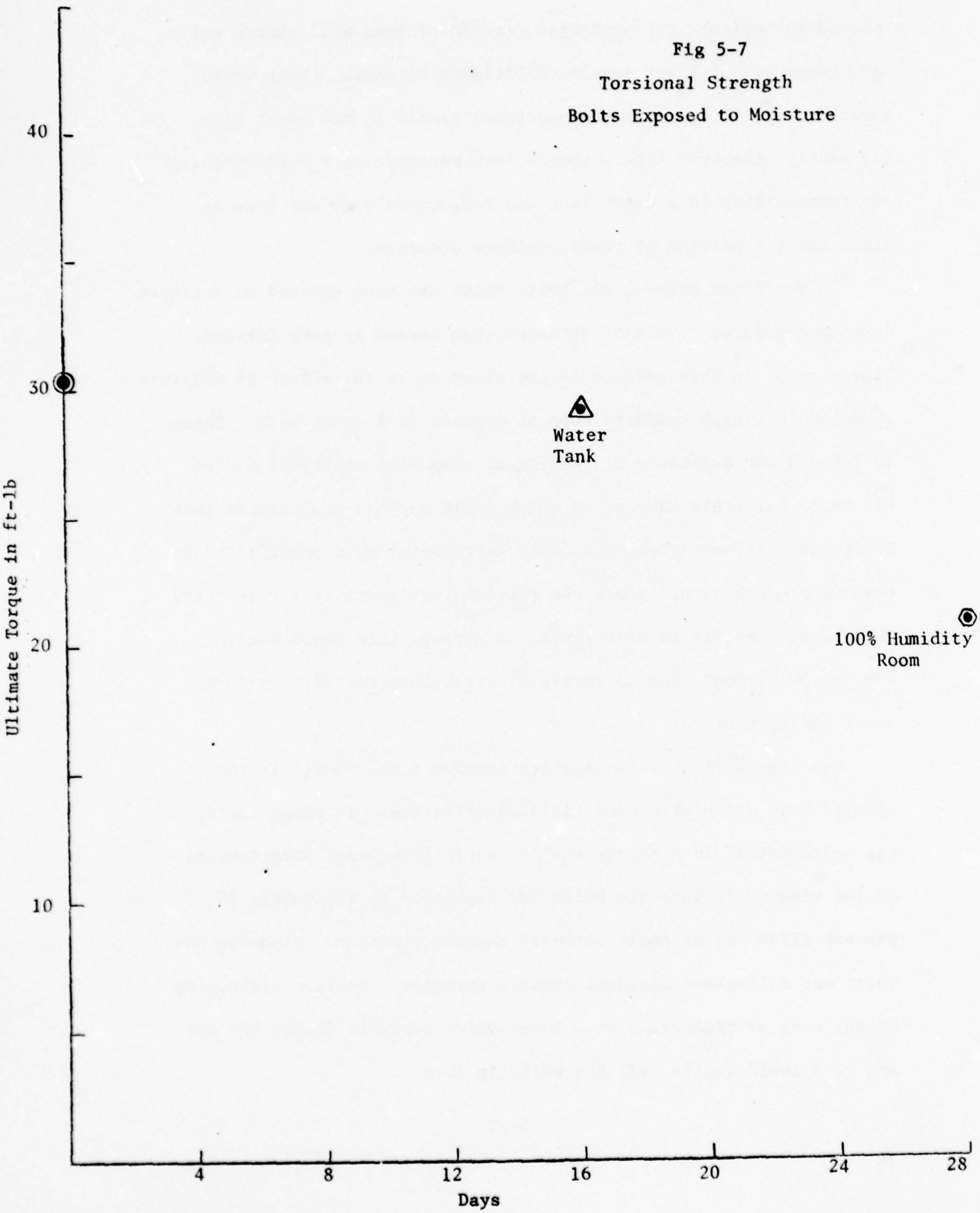


Fig 5-7
Torsional Strength
Bolts Exposed to Moisture
40
30
20
10
Ultimate Torque in ft-lb
Water
Tank
100% Humidity
Room
4
8
12
16
20
24
28
Days

CHAPTER 6

CONCLUSIONS

Wood and wood products are nonhomogeneous brittle materials. As a result, an engineer would expect to obtain somewhat inconsistent performance from wood as the levels of stress approach the ultimate strength. Recognizing this characteristic behavior of wood, the following conclusions seem reasonable as a result of the tests performed on steel split-ring shear connectors in laminated gusset plates.

a. The laminated, resin impregnated wood material has a stiffness larger than that normally experienced in wood products, hence a more brittle type failure should be expected.

b. The orientation of load to face grain has no significant effect on ultimate load carrying capacity of the split-ring connector.

c. The failure of the core area of the split-ring will occur at some depth less than the full depth of the split-ring groove, possibly along the weakest lamination within the wood material.

d. The shear connectors with 4 inch end distance do not develop any significantly greater strength than those with the 3 1/2 inch end distance for all load to face grain orientations.

e. The shear connectors with 4 inch edge distance do not develop any significantly greater strength than those with the 3.5 inch edge distance.

f. The ultimate load obtained will occur just prior to shearing of the core area of the split-ring connector.

g. The overall behavior of the split-ring connector with a constant end distance of 4 inches and variable edge distance closely parallel that of the connector with a constant edge distance of 2.75 inches and variable end distance.

h. The wood bolts will fail after the connection has reached its ultimate strength.

i. Bulging of some connections will occur only after deformation of 0.15 inches are developed and the specimen has developed its ultimate strength but has not completely fallen apart.

The results of the 111 bolt tests tend to support the following conclusions.

a. The average ultimate tensile strength is 5200 lb with a standard deviation of 440 lb for 3/4 inch diameter laminated wood bolts.

b. The average ultimate torsional strength is 30 ft-lb with a standard deviation of 6 ft-lb for 3/4 inch diameter laminated wood bolts.

c. Tension failure is frequently initiated by shearing the threads. Specifically, the threads may shear at a point not along the maximum core diameter. This may be true even when two full nuts are used to secure the bolt.

d. The exceptionally lose fit of bolt and nut probably is a contributing cause to the lower average tensile strength when compared with manufacturers data. One would suspect that in a more humid climate the bolts and nuts would fit more tightly and therefore provide greater contact surface and thread shear strength. This is partially

supported by the increased strength developed after the bolts had been exposed to moisture for some period of time.

e. Bolts subjected to tensile stresses will most probably fail by stripping of the threads, some bolts will break at a point roughly 2 inches from the end of the bolt. This corresponds to that point where the inside nut and bolt come together. Few bolts are likely to fail in tension in the middle third of the bolt length.

f. Bolts subjected to pure torsion are likely to display the characteristic spiral failure. Almost all of the bolts will fail in torque in the middle third of the bolt length.

g. Torsion failure will be initiated in the resin matrix by delamination of the wood layers. Only after considerable twisting will it be possible to fail the actual wood fibers.

h. The wood bolts have sufficient tensile strength for proper field installation. However, as the tensile forces increase in the bolt, the bolt and nut develop sufficient friction and freeze. Hence the bolt may fail in twisting if excessive torque is applied.

i. The laminated wood bolts behave as a bilinear material. Throughout the testing program, the average tensile strength remained relatively constant until the applied torque approached the torsion failure envelope. From that point on, only approximately 50 percent of the bolts had sufficient strength to resist the applied torque. Those bolts which did develop the torque also developed approximately the same levels of tensile strength as did those bolts tested in tension only.

j. The wood nuts and bolts may experience an average gain in weight of 6 percent after 28 days exposure to a high humidity environment. The moisture absorbed by the bolts will produce a tighter contact between the bolt and nut and therefore an initial increase in tensile strength. After prolonged soaking in a water bath, the bolt, however, develops a lower level of tensile strength.

k. The moisture absorbed by the bolts will produce a deterioration in the phenolic resins and therefore a reduced level of torsional strength.

l. Three quarter diameter bolts which are 31 inches long will elongate approximately 0.25 inches prior to failure under tensile loads. Hence if the wood beams and columns used in a structure are likely to swell more than 0.20 inches in width due to changes in climatic conditions, then adjustments must be made in the tightness of the bolts as the average bolt will fail when the elongation approaches 0.25 inches.

m. After applying a load duration factor of 1.65 to the average ultimate tensile strength and average ultimate torsional strength, as established in the laboratory, the long term strengths reduce to 3150 lb in tension and 18.5 ft-lb in torque. Applying a factor of safety of 2, the above estimated long term strength values reduce to an allowable tensile strength of 1575 lb and an allowable torsional strength of 9.25 ft-lb.

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2. Timber Construction Manual, American Institute of Timber Construction, Second Edition, 1974.

3. Scholten, John A., Timber Connector Joints: Their Strength and Design, Department of Agriculture, Washington, D.C.

4. ASTM D1761-68, Standard Methods of Testing Metal Fasteners in Wood.

APPENDIX A

MANUFACTURERS DATA

PERMALI EH
HIGH STRENGTH PHENOLIC LAMINATE

This unique product is a phenolic laminate made from carefully selected thin beech veneers These wood layers are impregnated under vacuum with a special synthetic resin and then densified through the application of heat and pressure. The result is Permali grade EH, a homogenous material that combines the great strength and toughness of wood fibers with the excellent stability and dielectric properties of the most advanced thermosetting resins.

PROPERTIES

Dielectric Strength . . . Permali EH was developed for and finds its principal use in high voltage electrical equipment.

High Strength/Weight Ratio . . . with a specific gravity of 1.3 it has tensile strength of 14 tons per square inch . . . a strength/weight ratio equal to high tensile steel.

Dimensionally Stable . . . since it is fully resin-impregnated and densified, water absorption is very low and dimensional stability is good.

Resistant to Abrasion . . . more resistant than quartz, it has a lower rate of wear than many metals.

Resistant to Heat and Weather . . . *suitable for prolonged use in all climates and weather . . . may be used continuously at temperatures of 105°C and intermittently to 150°C*

Retains Strength at Cryogenic Temperatures . . . retains about 80% of mechanical strength at −192°C (−314°F) . . . compressive strength (perpendicular to the face) actually doubles at cryogenic temperatures.

Completely Non-Magnetic . . . Naval Ordnance Laboratory tests indicate magnetic permeability is less than 1.004 . . . in another test after being subjected to a 1.4 kilogauss field, a Permali EH sample recorded a residual field of less than .01 gamma on a Varian Assoc. Rubidium Vapor Magnetometer . . . motion in the magnetic field of a coil wrapped on a Permali EH frame will not produce eddy currents.

Resistant to Chemicals . . . unaffected by continuous immersion in oils and fats . . . resists attack of mild acids and alkalis.

Attenuates Fast Neutrons . . . a most efficient structural material for neutron shielding . . . can be fabricated to close tolerances and can be operated at relatively high temperatures without deformation or loss of shielding properties.

QUALITY CONTROL

All Permali EH is processed under tight controls. Daily tests are normal routine, and continuous checks on processing operations maintain these high standards. The electrical, mechanical and physical properties detailed on page 4 are *averaged* from production-run materials tested on a continuous basis for more than a decade.

ADVANTAGES

When compared with NEMA-grade cellulose-base phenolic laminates, Permali EH is:

- equal electrically
- superior mechanically
- generally less expensive

When compared to NEMA-grade glass laminates, Permali EH costs only about 35% as much . . . a significant consideration. A further saving is made due to ease of machining. Also, fabricating charges are normally 50% less than for glass laminates.

Variable lamination arrangement. Unlike cotton or glass cloth, Permali's thin wood veneers contain unidirectional fibers. By varying the grain direction of the laminations, the production of several types of Permali EH with different mechanical properties can be manufactured to give you strength where you need it.

Structural advantages. Permali EH provides a higher modulus of elasticity than other phenolic laminates. Designers and fabricators can benefit, therefore, by *using a reduced* cross section, or by providing greater rigidity with the same cross section. The latter is a very *important consideration* in the construction of large insulating structures.

TYPES OF PERMALI EH

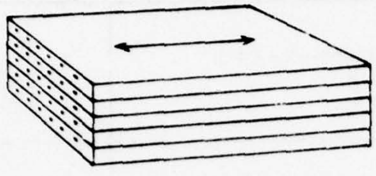
Six symbols completely describe any type of Permali EH, as follows:

Grade	E for most applications
Species of wood	H is Beech
Type	Laminar orientation (see p. 3)
Veneer thickness	5 is 1/32" 7 is 1/16"
P	Surface as pressed
M	Surface machined for closer tolerances
Surface finish	—Unvarnished 0 Edges varnished (special cases only) 1 Transformer oil finish (threaded parts) 4 Standard air drying electrical varnish. Excellent anti-tracking properties

EXAMPLE: EH65P4 Electrical grade Permali made from cross laminated beech veneers, 1/32" thick, press finish, with standard electrical varnish coating.

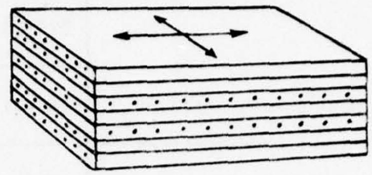
TECHNICAL DATA

GENERAL APPLICATION



TYPE 5—Uni-directional laminae
For components stressed in tension, flexure or torsion
Lengths to 170"
Widths to 10"

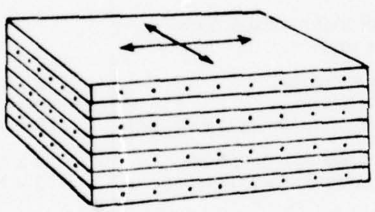
Thickness	Type 55	3/16" to 1"
	Type 57	1/2" to 3"



TYPE 6—Cross Laminated
For panels and components in compression or for parts stressed in more than one direction
Sizes to suit most applications

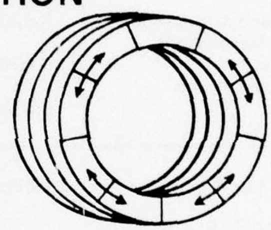
Thickness	Type 65	3/16" to 1"
	Type 67	1/2" to 6"

SPECIAL APPLICATION

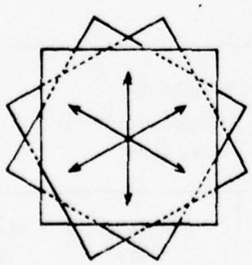


TYPE 2—25% cross laminated
For tensile applications requiring higher shear strength along the major axis
Lengths to 170"
Widths to 20"

Thickness	Type 25	3/8" to 1"
	Type 27	1/2" to 4"

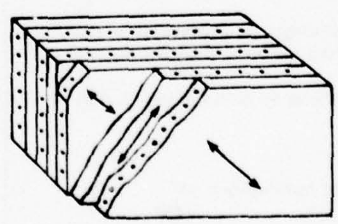


TYPE 7—Laminae tangential to periphery
For non-impregnated transformer clamping rings
Minimum I.D.—12"
Maximum O.D.—110"
Minimum Radial Wall—1 1/2"
Maximum Radial Wall—14"
Ratio of Wall to Thickness—12:1 Maximum
Thickness—3/4" to 2 1/2"



TYPE 3—Radially disposed laminae
For making silent gears. This arrangement achieves uniform tooth strength.
Maximum diameter: 12"

Thickness	Type 35	3/8" to 1"
	Type 37	1" to 4"



TYPE 8—Laminae 45° to major axis
For increasing the electrical strength of components along the major axis where mechanical requirements are not critical
Sizes restricted

Thickness	Type 85	1/2" to 1"
	Type 87	1" to 3"

MECHANICAL PROPERTIES

	TYPE 5	TYPE 6
Tensile Strength, psi, Lengthwise	28,000	15,000
Compressive Strength, psi		
Perpendicular to laminations	17,000	30,000
Parallel to laminations and grain	17,000	22,000
Flexural Strength, psi (flatwise)		
Lengthwise	32,500	18,000
Crosswise	—	15,000
Shear Strength, psi		
Parallel to grain and laminations	3,500	3,500
Perpendicular to laminations, parallel to grain	4,800	7,200
Perpendicular to grain and laminations	9,500	7,200
Bonding Strength, lbs., Cond. A	1,500	1,400
Impact Strength, Izod, ft lb/in of notch		
Perpendicular to face, lengthwise	5.4	3.4
Perpendicular to edge, lengthwise	5.0	1.6
Modulus of Elasticity	2.5×10^{6}	2.0×10^{6}

PHYSICAL PROPERTIES

Water Absorption—%—24 hr	
Thickness ½	1.00
Thickness 1	0.75
Intermittent operating temperature	150°C (302°F)
Continuous operating temperatures	
In Oil	105°C (221°F)
In Air	105°C (221°F)
Specific Gravity	1.30
Hardness (Rockwell H Scale)	90-100
Specific Heat	0.4
Coefficient of thermal expansion— centigrade units	
Type 5 Lengthwise	8×10^{6}
Crosswise	69×10^{6}
Perpendicular to laminations	113×10^{6}
Type 6 Parallel to laminations	15×10^{6}
Perpendicular to laminations	113×10^{6}
Thermal Conductivity—cal/cm/°C/sec	
in plane of laminations—lengthwise	5.6 ~~56.0~~ $\times 10^{4}$
in plane of laminations—crosswise	3.6×10^{4}
across plane of laminations	3.4×10^{4}

ELECTRICAL PROPERTIES

Dielectric Strength (step-by-step @ 25°C— see Permali leaflet ETL-A for details)	
Perpendicular to laminations (V/M) ⅛"	360
¼"	250
½"	175
Parallel to laminations KV	65
V/M	87
Power Factor—%—60 Hz	1.9
10^{3} Hz	3.0
10^{6} Hz	5.0
Dielectric Constant—60 Hz	4.5
Specific Resistance—ohms/cm³	2×10^{12}

IMPULSE STRENGTH—
Typical Values for Flashover in Air,
1½ x 40 Wave Form

Distance Between Electrodes	Negative Wave	Positive Wave
12"	210 KV	150 KV
24"	435 KV	380 KV
36"	620 KV	560 KV

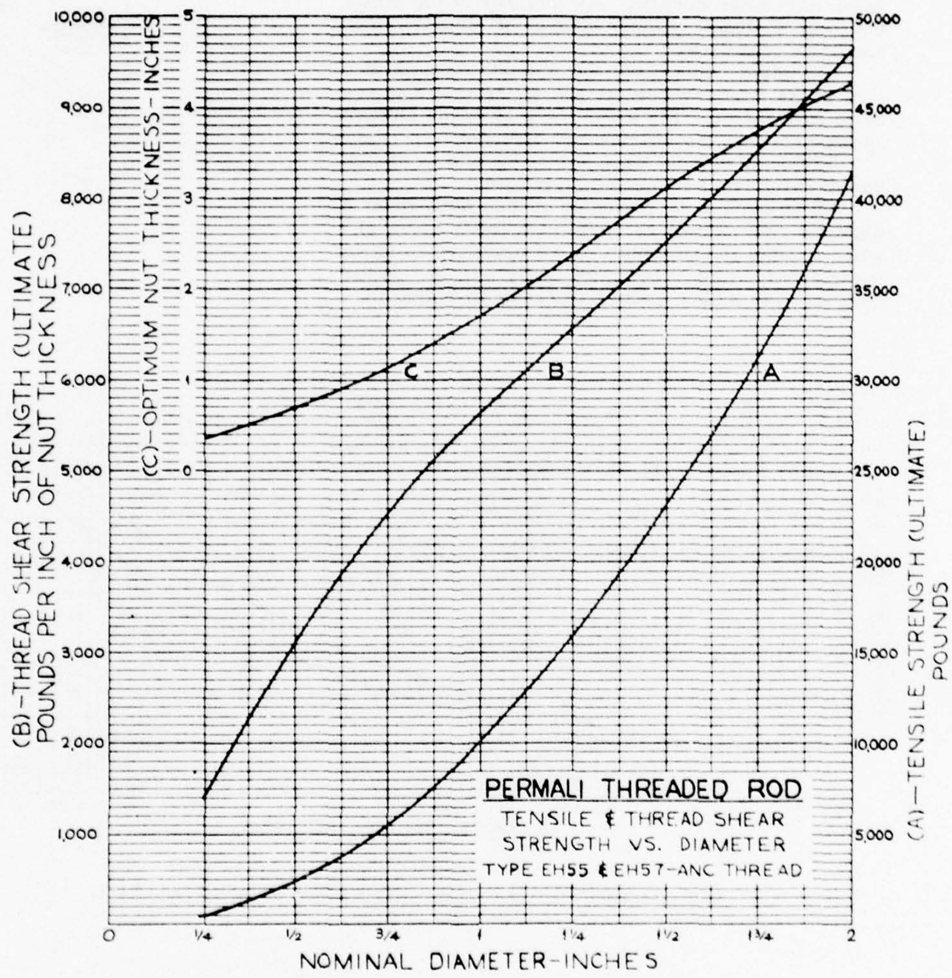
All data are based on applicable NEMA/ASTM test standards

PERMALI Information Sheet

THREADED FITTINGS-ANC

The curves below are for use in the design of threaded Permali parts employing ANC threads. In order to develop a thread shear strength equal to the ultimate tensile strength of the stud, a thread length equal to the "optimum nut thickness" must be engaged. A shorter thread engagement will result in a pro rata reduction in strength of the assembly.

***ANC threads are normally recommended for diameters to 1"-1¼". For greater diameters ANF threads should be used.* (See Threaded Fittings-ANF)**



NOTE: CURVES REPRESENT AVERAGE RESULTS OF ACTUAL TESTS

USE OF CURVES

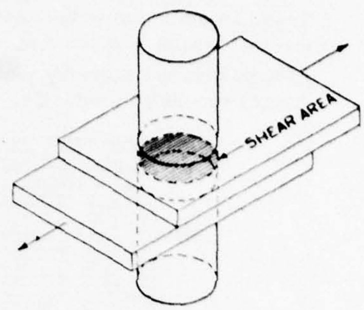
(a) To find ultimate tensile strength of a **Permali** threaded component read up from the desired diameter to 'Curve A' and then across to the right vertical scale.

(b) To find shear strength per inch of nut thickness or per inch of thread engagement, read up from the desired diameter to 'Curve B' and then across to the outer left vertical scale.

(c) To find nut thickness for maximum assembly strength read up from the desired diameter to 'Curve C' and then across *to the inner left vertical scale.*

Figures obtained from the curve are ultimate and suitable safety factors should be applied.

THREADED FITTINGS-ANC



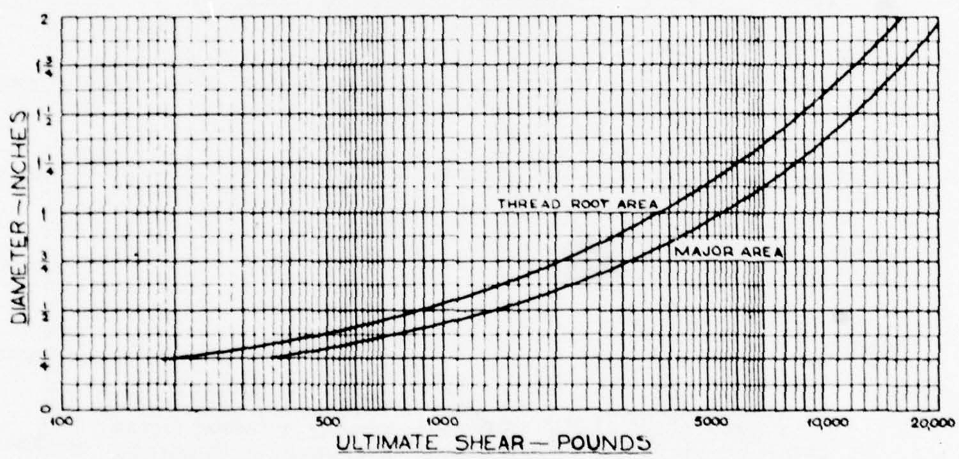
The curves below give the ultimate shear strength of round Permali sections (Types 55 & 57) in a plane perpendicular to the major axis, as illustrated by the drawing.

The data presented is for single shear. With many fittings double shear will occur and will permit the curve data to be doubled. An analysis of the fastening will indicate whether single or double shear should be considered.

The upper curve gives the ultimate strength of a stud in the threaded portion; i.e., at the root diameter of an ANC thread. The lower curve gives the ultimate strength through the full nominal diameter.

Additional data for larger diameters and or special thread forms will be supplied on request.

All strength data presented in this data sheet is ultimate. We usually recommend a safety factor of 4 when loading is uniformly applied and 6 when shock loading may occur. For particularly severe applications an even higher safety factor may be indicated.



ANC THREADED ROD
SHEAR PERPENDICULAR TO AXIS VS. DIAMETER

We invite your inquiries. Our technical staff is at your service and early consultation on design problems may save time and money.

PERMALI, INC.

PERMALI, INC., P.O. Box 718,
Mount Pleasant, Pa. 15666 (Pittsburgh District)
Phone 412/547-4581

PERMALI PACIFIC INC., Par Mac Industrial Park,
10930—116th Avenue NE, Kirkland,
Washington 98033 • Phone 206/822-0217

PERMALI (CANADA) LTD., 2870 Slough Street,
Malton, Ontario • Phone 416/677-2090

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PERMALI Information Sheet

The mechanical properties of PERMALI listed in our technical literature have been established and are maintained by laboratory tests carried out to N.E.M.A. or A.S.T.M. standards. However, all practical applications inevitably introduce stress concentrations — the effect of which is to limit the achievement of maximum ultimate strength.

The purpose of this data sheet is to suggest methods of calculation that have been proved in practice to produce conservatively accurate determinations of the ultimate strength of actual components.

PERMALI IN TORSION - Normally Type "5" is used. (See technical leaflet for type description)

When Permali rods are used in torsion, the determining factors are torsional strength for short rods and angular deflection for long rods. Since it is not possible to draw a sharp line of division, it is well to calculate both values for all designs.

The ultimate shear strength of Type 5 Permali rods in torsion may be taken as 4,500 psi. For gradual loading a safety factor of 4 should be used, and for shock loading, the factor of safety should be 6. In practice, therefore, the allowable working loads in shear would be 1,125 psi for gradual loads and 750 psi for shock loads.

Where angular deflection is a factor it may be calculated as follows:

$$\theta = \frac{583.6\ TL}{d^4\ G} = .00162\ \frac{TL}{d^4}$$

where:

θ = Torsional deflection (degrees)
T = Torsional moment (inch.lbs.)
L = Length (inches)
d = Diameter (inches)
G = Torsional modulus of elasticity — 3.6×10^5 psi

The allowable torsional moment for round rods may be calculated:

$$T = S \times 0.196d^3$$

where:

T = Torsional moment (inch-lbs.)
S = Allowable shear stress (psi)
d = Diameter (inches)

In the case of square shafts, the following should be used:

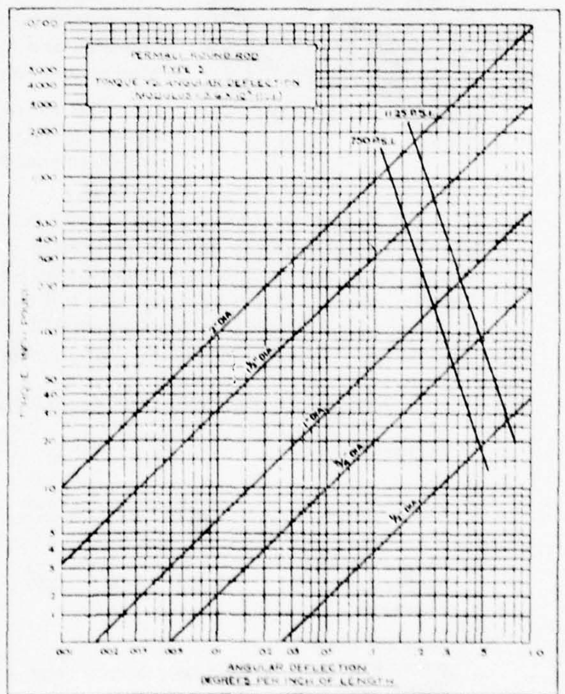
$$T = S \times 0.2083b^3$$

$$\text{and } \theta = 407.4\ \frac{TL}{Gb^4} = .00113\ \frac{TL}{b^4}$$

where:

b = (inches)

Other symbols as above



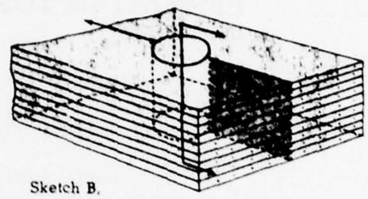
COMPONENTS IN TENSION

RECTANGULAR SECTION PERMALI PARTS—(Types 2, 5 and 6)

Sketch A.

When bolts, pins, or rivets are used to attach metal end fittings to a link or bar the stress concentration around the bolt holes and at the sharp corners of the component will cause it to fail at a tensile stress well below the theoretical value. The shear values are similarly reduced.

Tests show that the frictional grip of tightly bolted end fittings will carry between one-third and one-half of the total load in failure. As there is a substantial "human element" in assembly tightness many designers prefer to ignore the frictional grip. Separate figures are therefore quoted in Table 1 for both types of load transfer. Note that the only difference between tightly bolted and pinned end fittings is in the shear values, since tensile failure usually occurs at the inner end of the fitting when the Permali is carrying the whole tensile load.

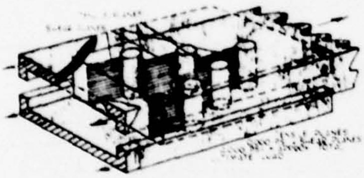


Sketch B.

When using the tabulated data the following considerations should be recognized:

(1) *Tensile Strength* should be calculated on the reduced cross-section occurring at the innermost bolt or pin holes. (See shaded area in Sketch A.)

(2) *Shear Strength* should be based on the failure in single shear or splitting of the material between the bolt holes and the end of the component (see shaded area shown in Sketch B). When several holes are used as shown in Sketch C, failure will usually occur by shearing of the whole triangular portion indicated and the shear figures quoted should be applied to the total area of failure.



Sketch C

The use of box section end fittings or channel plates (as shown in Sketch C) which gives side support to the Permali is recommended and will substantially increase the failing load in shear.

(3) *Maximum bearing pressure* (calculated on the projected area of contact) is the stress at which local crushing and comprehensive failure of material in contact with the bolts will occur. The values quoted are conservative, but care must be taken to use pins or bolts of such size and material that bending stresses will cause no appreciable distortion. If the pins bend or distort, local sttessing of the Permali will take place, and the strength of the assembly will be reduced. High tensile steel bolts and pins are recommended.

TABLE 1. FAILING LOADS: RECTANGULAR SECTION PERMALI RODS

Type of Material:—	EH57 & EH55			EH67 & EH65			EH27 & EH25		
Type of Loading:—	Tensile	Shear *	Bearing Pressure	Tensile	Shear*	Bearing Pressure	Tensile	Shear*	Bearing Pressure
Pinned end fittings. Ultimate figure to be expected p.s.i.	10,000	4,000	14,000	6,000	9,600	14,000	7,500	5,300	14,000
Bolted end fittings well tightened up. Ultimate figure to be expected p.s.i.	10,000	6,000	14,000	6,000	12,000	14,000	7,500	7,500	14,000

* These figures are for single shear and should not be doubled. Do not assume double shear will occur.

PERMALI ROUND RODS— (Type 5)

In designing metal end fittings for Permali rods of circular section, two points should be considered:—

(1) In common with other insulating materials Permali is notch sensitive, and it is important to avoid stress concentration as much as possible.

(2) The ultimate strengths of Permali differ widely between tension, shear and compression. The proportions of a balanced design will, therefore, differ from those of a similar metal part.

Nevertheless, the use of conventional, threaded end fittings is recommended for normal applications: ANC for smaller sizes and ANF for sizes over about one inch. While accurately fitting 'round' or 'roll' form threads are actually stronger, their use requires special form tools, taps, and gauging equipment. This expense is seldom warranted except for volume production.

TABLE 2

FAILING LOADS : TYPE 5 "PERMALI" ROUND SECTION RODS	Size of Rod	
	Diam. less than 1 inch Thread form ANC	Diam. over 1 inch Thread form ANF
 $\pi d L$ Actual shear strength	2,500 p.s.i.	1,800 p.s.i.
 $\frac{\pi d^2}{4}$ Actual tensile strength	18,000 p.s.i.	18,000 p.s.i.

These figures are intended to apply to "Permali" Studs fitted with either Type 6 "Permali" or steel nuts.

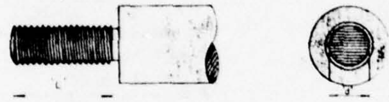


Fig. 1

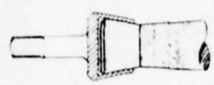


Fig. 2 (a)

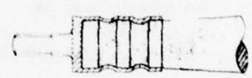


Fig. 2 (b)

The reduction in tensile strength caused by stress concentrations at the base of AN threads is not as severe as that caused by holes in flat links, and the ultimate tensile strength of Permali threaded rods is approximately 18,000 psi calculated on the cross sectional area at the base of the thread. $\frac{\pi d^2}{4}$ (See Table 2)

(Fig. 3(a)

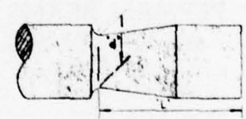


Fig. 3(b)

However, the ultimate tensile strength of the core will usually exceed the shear strength of the threads. This may be assessed on the calculated area (π DL) of the cylinder at the base of the thread which will be sheared when the nut is pulled off. For rods less than 1" diameter a shear strength of 2,500 psi may be assumed. For diameters greater than 1" use a figure of 1,800 psi (see Table 2). The ultimate failing load of the assembly will be either this load or the calculated ultimate tensile load, whichever is smaller.

For threaded Permali rods, whether used with Permali or metal nuts thread engagement (L, Fig. 1) should be greater than the nominal diameter. For most applications L should be $1\frac{1}{2}$ D and can be further increased with advantage when the calculated shear strength is less than ultimate tensile strength.

Another form of end fitting consists of a steel tube or cap, rolled or swaged into shallow grooves turned near the ends of the Permali rod (see Figs. 2(a) and 2 (b)). The limitation of quality inspection however dictates that the method should be utilized only where quantities are sufficient to permit testing to destruction of a reasonable number of samples.

A similar fitting employs a split ring or other component inserted in a groove cut in a round Permali rod. This transmits the load by putting the cylinder of material between the groove and the end of the rod in shear. Generally the effect is similar to that obtained with screw threads, but stress concentration is more severe with only one groove.

Using a groove with a sharp corner, as in Fig. 3 (a), an ultimate shear stress of 1,200 psi should be used to calculate the failing load of the cylinder, π d L.

The use of a fairly large radius in the bottom corner of the groove, where the stress is concentrated, will raise the unit failing stress to 1,500 psi. Where a tapered fitting, as shown in Fig. 3 (b), is used, stress concentration is still further reduced and unit failing stress can be taken as 1,700 to 1,800 psi.

STRUCTURAL APPLICATIONS

PERMALI COLUMNS

Permali components acting as columns, as in the case of circuit breaker lift rods, are sometimes stressed alternately in tension and compression. Tensile characteristics are discussed on Pages 2 and 3. Since end fittings are normally attached in such a way that the columns can be assumed to have fixed ends, reaction to compressive forces is normally the same as for fixed columns such as occur in high voltage structures. Assuming fixed ends and the use of Type 5 Permali, the ultimate strength of columns may be calculated thus:—

When the slenderness ratio (ℓ/k) exceeds 150—

$$P = 98.8 \times 10^6 \times \frac{I}{\ell^2}$$

If the column is a square section, the above can be solved for Section size as follows—

$$b = \sqrt[4]{0.1213 \times 10^{-6} P\ell^2}$$

$$\ell > 43.3\ b$$

If the column is a round section, the following applies—

$$d = \sqrt[4]{0.206 \times 10^{-6} P\ell^2}$$

$$\ell > 37.5\ d$$

FORMULAE SYMBOLS

- P = buckling load—pounds
- ℓ = length in inches
- k = least radius of gyration—inches
- I = moment of inertia—inches⁴
- A = section area—square inches
- b = side of square—inches
- d = diameter—inches

When the slenderness ratio (ℓ/k) is less than 150—

$$P = \frac{A \times 18{,}000}{1 + 0.00025\,(\ell/k)^2}$$

When the cross section is unknown, this equation can only be solved by trial but, if a square section is assumed, the equation becomes —

$$P = \frac{b^2 \times 18{,}000}{1 + \frac{\ell^2}{334\ b^2}}$$

If a round section is used, the equation becomes:

$$P = \frac{14{,}140\ d^2}{1 + \frac{\ell^2}{250\ d^2}}$$

SAFETY FACTORS Solution of the above formulae produces ultimate strength. Minimum safety factors of 4 for static loading and 6 for shock loading are recommended.

PERMALI BEAMS

Having relatively high moduli of elasticity and rupture, Permali is an ideal structural material for beams which must have dielectric or non-metallic properties. For calculations use standard formulae with the properties for Permali listed in the technical leaflet. End fittings should be carefully designed to provide adequate bearing and shear areas.

PERMALI IN SHEAR

The shear strength of Permali varies with the type employed and the direction of applied stress. This characteristic as it applies to parts with bolted and threaded fittings is discussed on Pages 2 and 3. However, in designing for shear forces, consideration should be given to the following basic principles:

1. It is preferable to drill holes in the face rather than the edge.
2. With Type 5 beams and columns it is preferable to apply external shear forces perpendicular to the axis.
3. With Type 6 members in shear it is preferable to apply the force on the edge and perpendicular to the face.

PERMALI IN COMPRESSION

Permali Type 6 should normally be selected but many components stressed in compression are also loaded in other directions, and this may determine the type of material used.

STRENGTH WEIGHT COMPARISON

	Specific Gravity	Tension	Compression	Shear	Bending
Permali	1.30	1	1	1	1
Structural Steel	7.85	0.20	0.16	0.52	0.19
Duralumin	2.79	0.55	0.41	1.36	0.50
Magnesium Alloy (ASTM 6)	1.77	0.71	0.77	1.48	0.66
Douglas Fir	0.46	0.73	0.30	0.34	0.50

Based on Yield Point

MA8-3M-965
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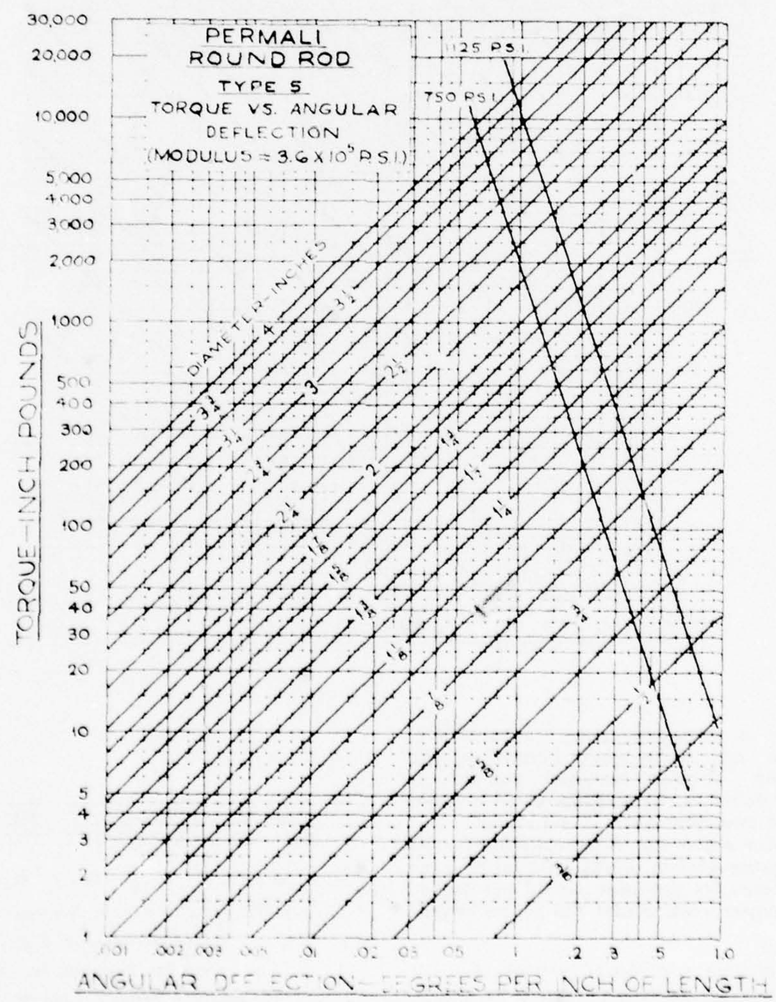
PERMALI Information Sheet

PERMALI IN TORSION
ROUND SECTION

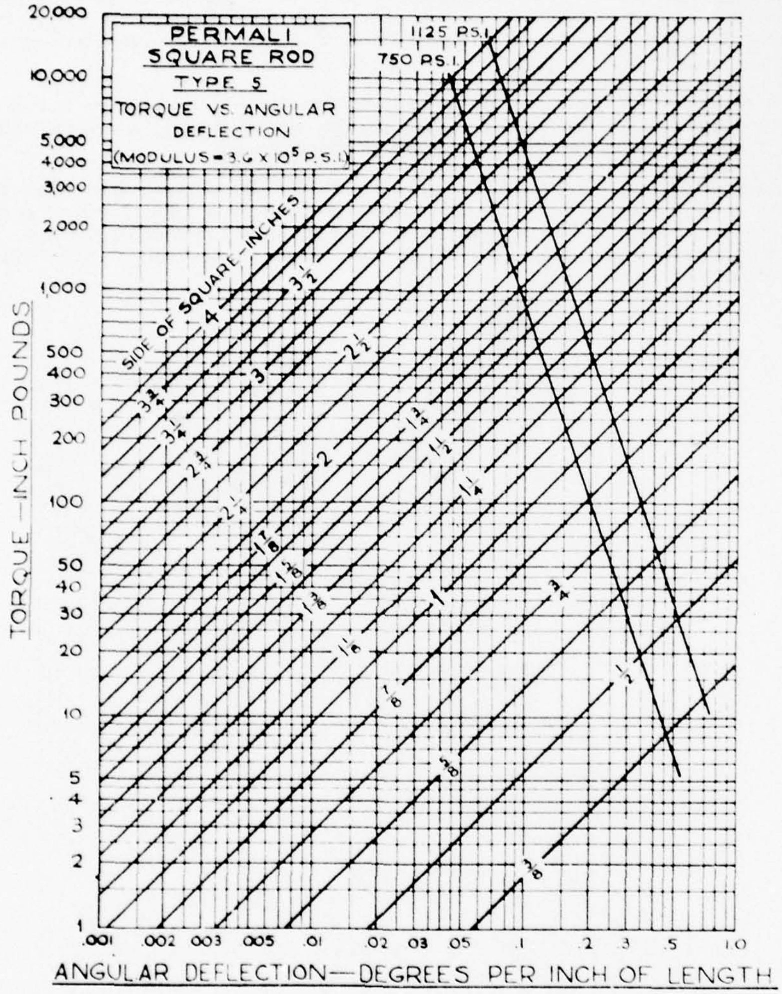
Permali types EH55 and EH 57 are frequently specified for insulating operating shafts subject to torsional loading. The curves on this sheet have been prepared to aid in the accurate selection of section dimensions. The information shown is recommended as a basis for design.

Round section shafts are commonly used in conjunction with driving pins or flats at the point of torque application. A preferred method utilizes square section ends providing positive contact with end fittings and minimizing stress concentration.

As explained in the "Mechanical Design Data" section, the ultimate shear stress for torsional loading is 4,500 psi and the Torsional Modulus of Elasticity is 3.6 x 10 psi. It is recommended that safety factors of 4 for static loading and 6 for impact loading be applied. This results in a maximum working stress of 1125 psi and 750 psi respectively. These limits are well defined on the curves.



PERMALI IN TORSION
SQUARE SECTION



Although not as commonly used as round sections, there is logic in the use of Permali square section shafts. Greater torsional strength is obtained per dollar of cost and the exact angular placement of attaching parts is simplified.
The curves above give the data necessary for the design of square section shafts. As with round Permali sections, the designer should not exceed 1125 psi for static loading and 750 psi for impact loading.

Permali engineering and design service is freely available for special problems related to specific applications.

MTLC 5M 162

PERMALI
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Toronto 18, Ontario. Telephone Belmont 3-2179

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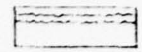
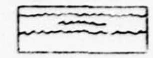
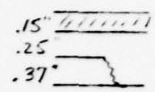
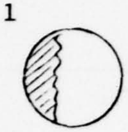
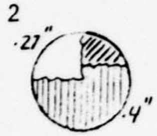
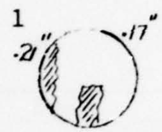
APPENDIX B

TYPICAL FAILURES OF SPLIT-RING SHEAR CONNECTORS IN LAMINATED WOOD GUSSET PLATES

Average Depth of Shear Failure Left Side	Average Depth of Shear Failure Right Side	No. of Laminations Crossed ** Left	No. of Laminations Crossed ** Right	Bolt Failure	Viable Cracks*	Remarks
.28	.15	0	0	Complete	L 3.7 & 4.3 R 4.3 & 4.4 Depth L .27 R .16	Right side of driver block failed at a depth of .15" & .26", major horiz. crack at 4.5" from top. Ring warped.
.41	.38	1 	0	Cracked	L 4.0 & 4.3 R 2.8 & ___ Depth L .16 & .39 R .15	Double split on left side.  bottom view Double split on right side. Ring warped. 
.17	.25	0	3 	Complete	L ___ & 3 R 3.2 & 3.9 Depth L .17 R .5	Ring warped. Some splintering of wood on right side.
.15	.15 & .37 & .25	0	2 	Complete	L 2.3 & 3.4 R 3.1 & ___ Depth L .15 R .26	Ring warped. Some splintering on right side. Right side, only top layer broken completely away.
.17	.19	0	1 	Complete	L 3.7 & 3.3 R 2.4 & 4.4 Depth L .16 R .22	Some splintering on both sides. Ring warped.
.18	.27	0	1 	Complete	L 2.9 & 3.7 R 2.3 & 4 Depth L .23 R .11	No splintering of wood. Ring warped.
.39	.16	1 	2 	Complete	L 4.3 & 4.5 R 2.4 & 4 Depth L .38 R .2	Some splintering of wood on right side. Ring warped.

Average Depth of Shear Failure: Left Side	Average Depth of Shear Failure: Right Side	No. of Laminations Crossed **: Left	No. of Laminations Crossed **: Right	Bolt Failure	Viable Cracks*	Remarks
.18	.28	1 	2 	Complete	L 1.9 & 3.9 R 4 & 2.2 Depth L .15 R .2	Right side of driver block failed. Ring warped. Top side of driver block split, depth .28". Avg. dist. = 4.8" from top.
.18	.16	0	0	Complete	L 2.3 & 4 R 3.6 & 2.3 Depth L .21 R .31	Some splintering of wood lamination on right side. Ring warped.
.18	.15	0	0	Partial on left side only	L 2 & 4.3 R ___ & 4.1 Depth L .2 R .15	Some splintering of wood lamination on left side. Ring warped.
.5	.27	1 	1 	No	L 4 & 3.1 (R 3.4 & 4) driver Depth L .5 R .0	Right side of driver block failed. Some splintering of wood on right side. Ring slightly warped.
.33	.17 half layer split 2 laminations or .11" lower	2 	1 	Complete	L 4.2 & 3.8 R 3.1 & 4.0 Depth L .16 R .16	Some splintering of wood on left side. Ring warped.
.19	.50	1 	0	Cracked only right side	L 4.0 & R 2.5 & 1.8 Depth L .16 R .15	Some splintering of wood on left side. Slight warping of ring. Bottom of right side split at .5". Crack directly under bolt.

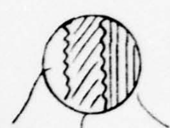
Average Depth of Shear Failure		No. of Laminations Crossed **		Bolt	Viable	
Left Side	Right Side	Left	Right	Failure	Cracks*	Remarks
.17	.18	0	0	Complete on right side - cracked on left side	L 4.4 & 4.6 R 3.6 & 2.9 Depth L .18 R .27	Some splintering of wood. Warping of ring.
.27	.18	0	0	Complete	L 2.2 R 1.7 & 4 Depth L .20 R .16	Some splintering of wood lamination on right side. Ring warped.

Notes:

All specimens showed evidence of crushing above ring on driver block and below rings on side plates.
Unless noted on individual specimen, driver block appeared to be in tact.

*Visible cracks are horizontal cracks, dimension given in inches is from bottom of side plate; depth in inches is measured from face of plate containing the split ring.

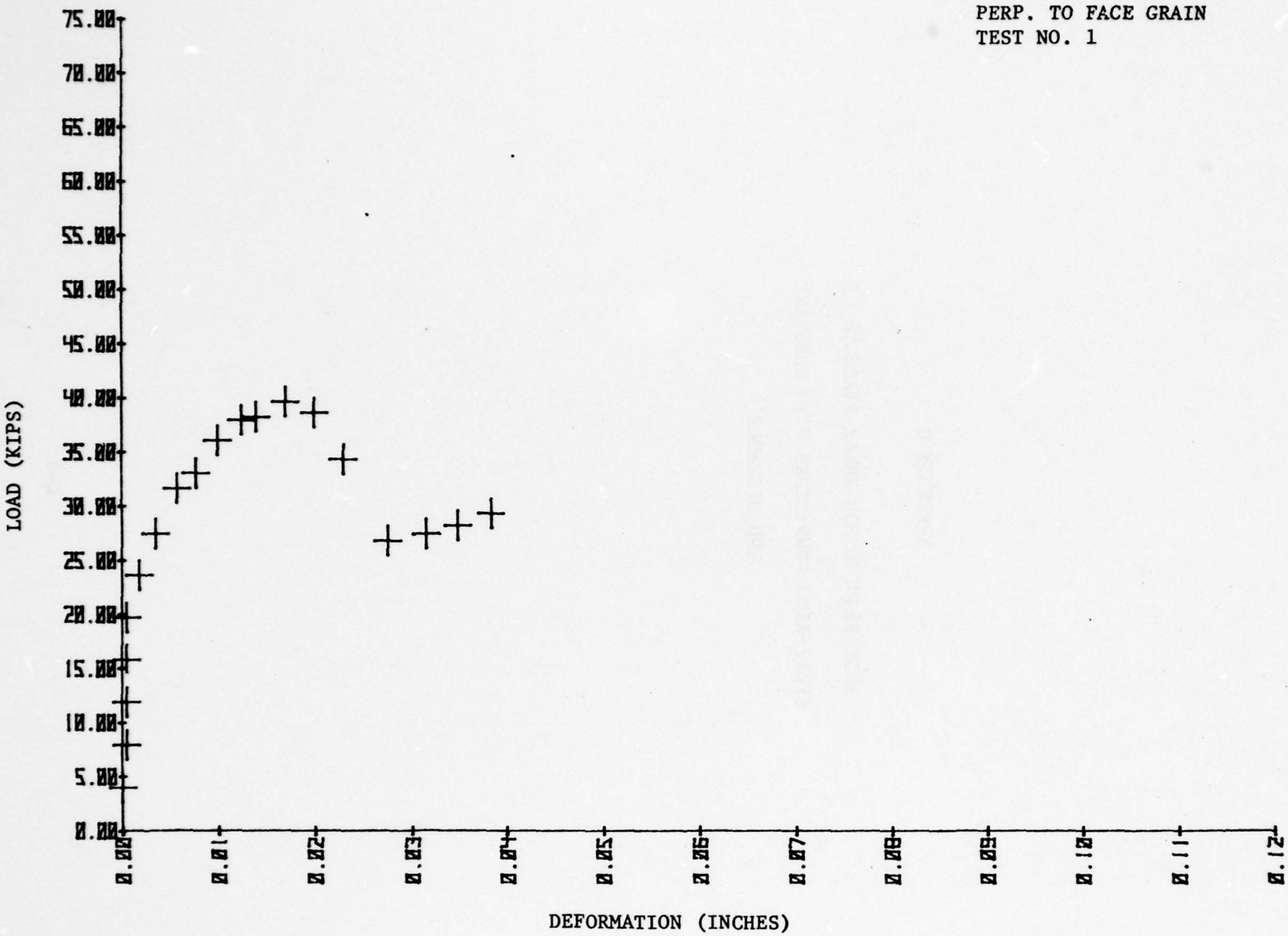
**

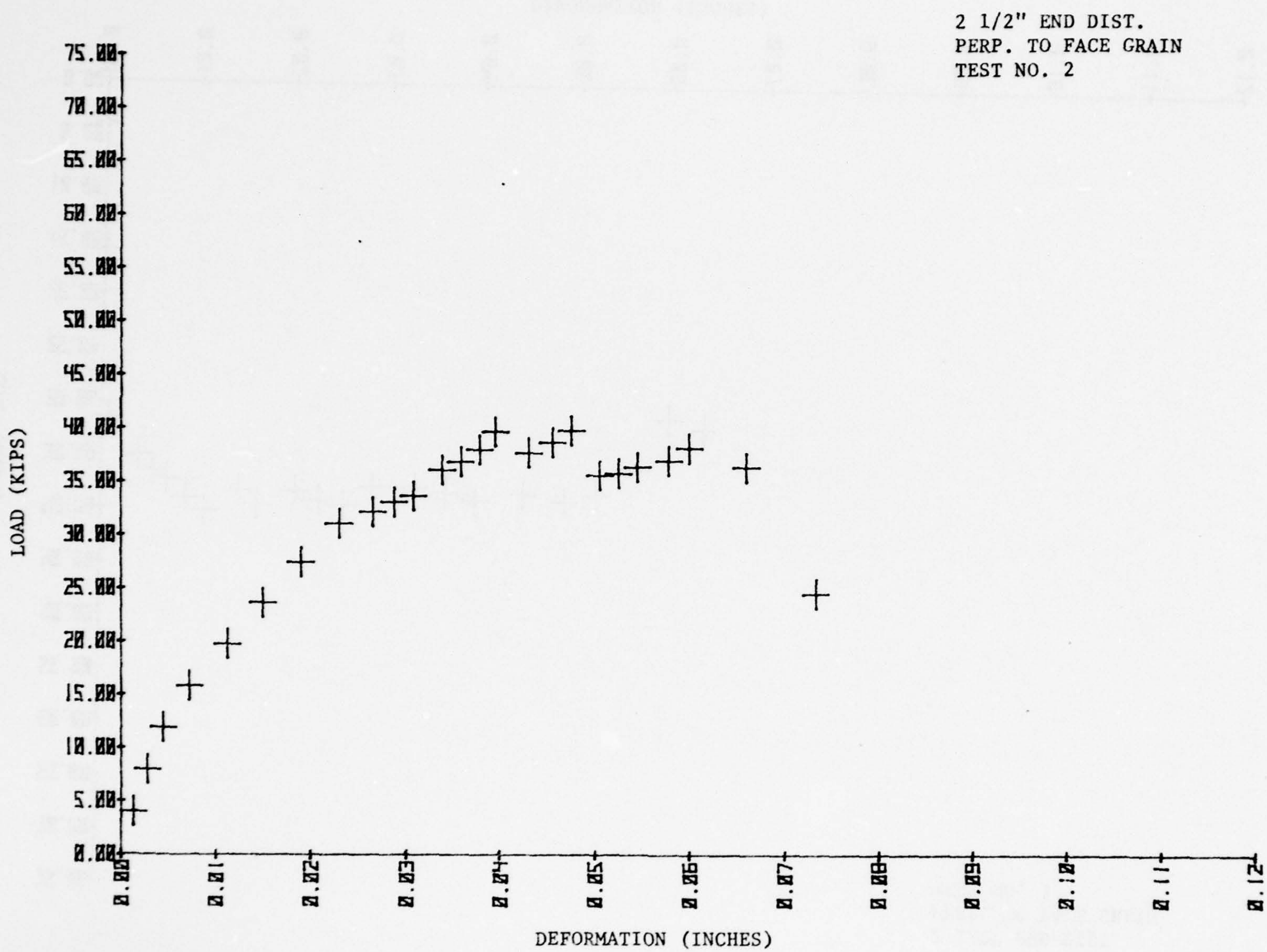


APPENDIX C

TEST RESULTS FOR SHEAR STRENGTH OF SPLIT-RING CONNECTORS WITH CONSTANT END DISTANCE

2 1/2" END DIST.
PERP. TO FACE GRAIN
TEST NO. 1




2 1/2" END DIST.
PERP. TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
DEFORMATION (INCHES)
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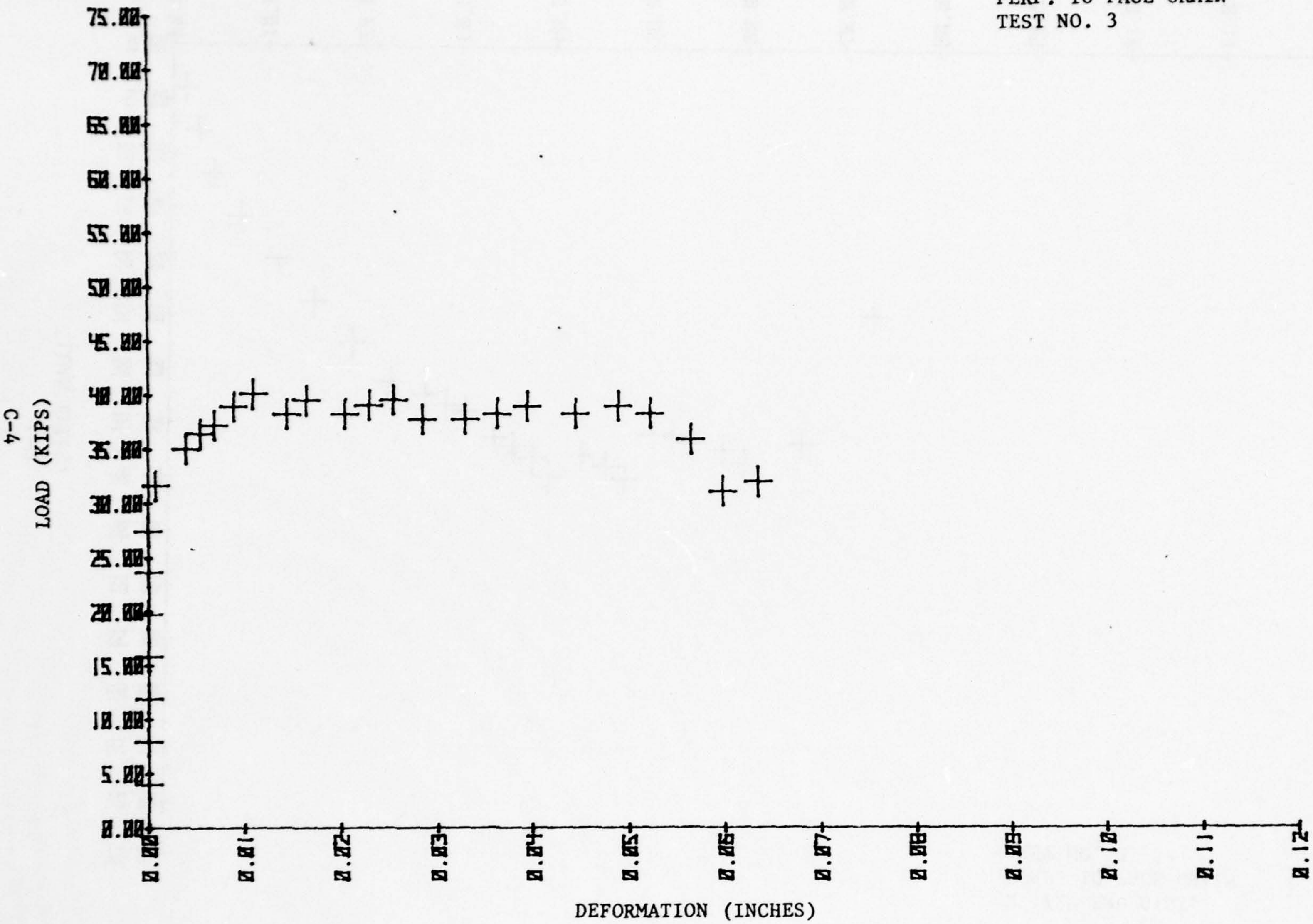
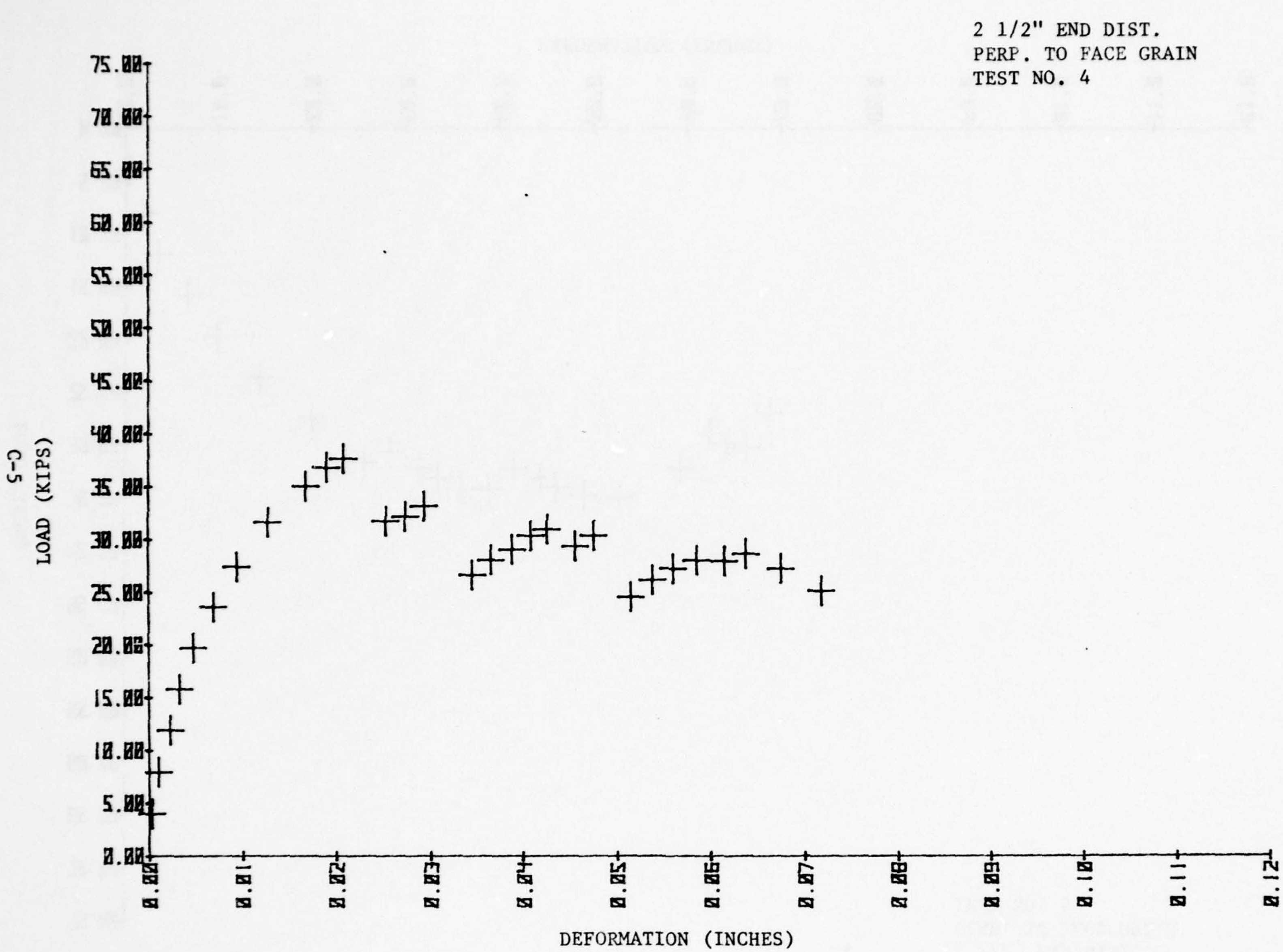
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12

2 1/2" END DIST.
PERP. TO FACE GRAIN
TEST NO. 3

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PERP. TO FACE GRAIN
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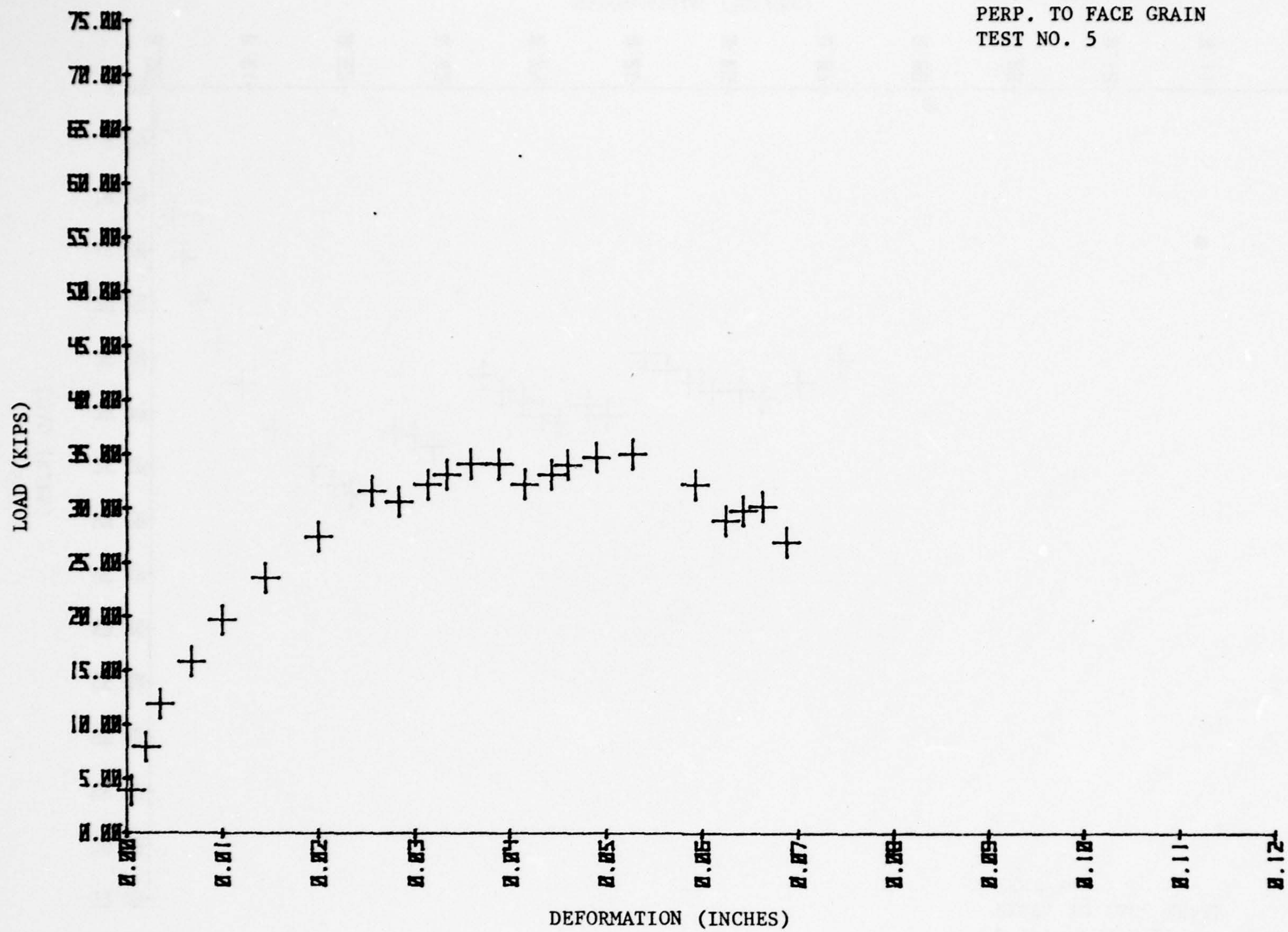
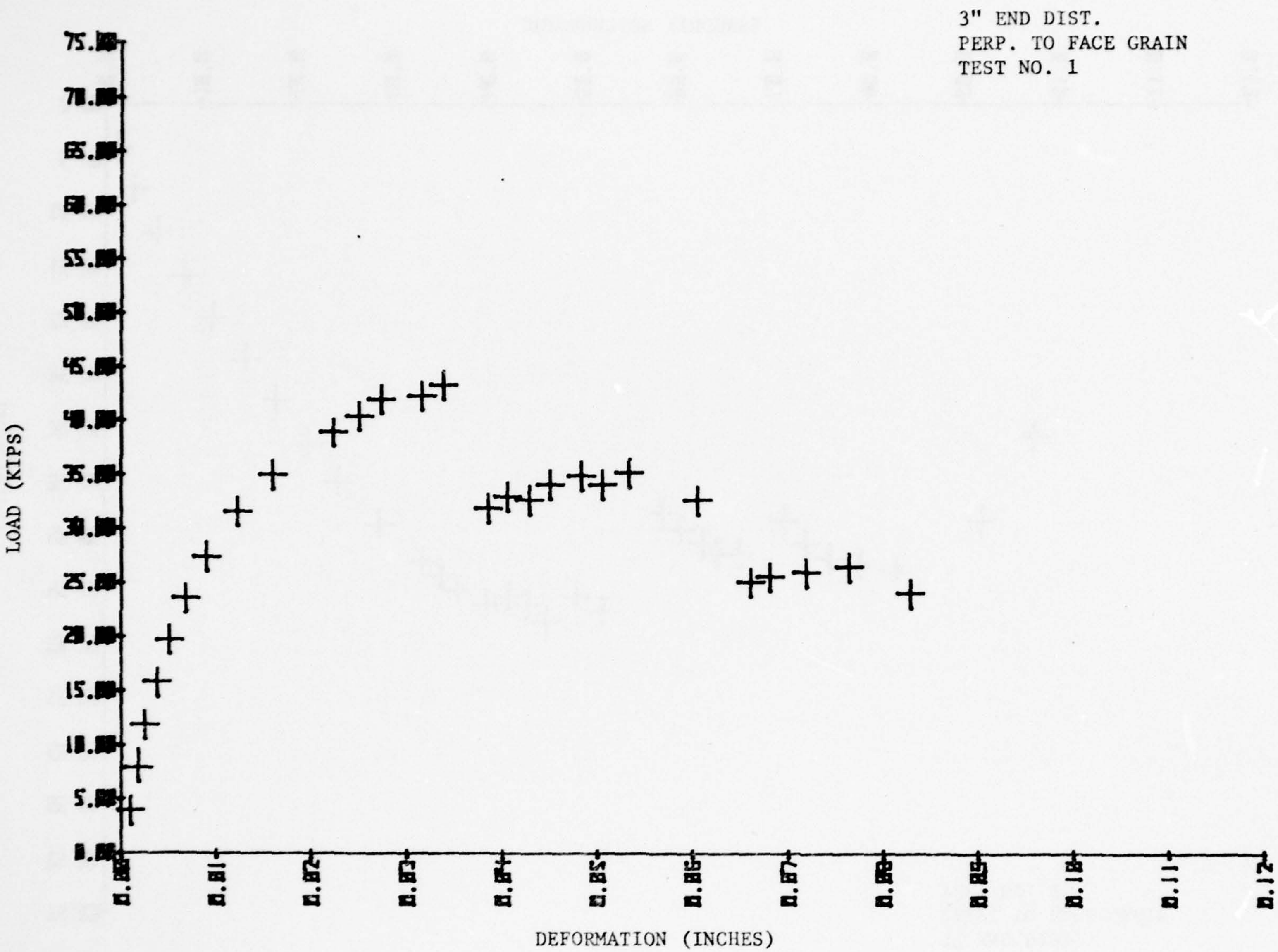
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)

2 1/2" END DIST.
PERP. TO FACE GRAIN
TEST NO. 5




3" END DIST.
PERP. TO FACE GRAIN
TEST NO. 1
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55.00
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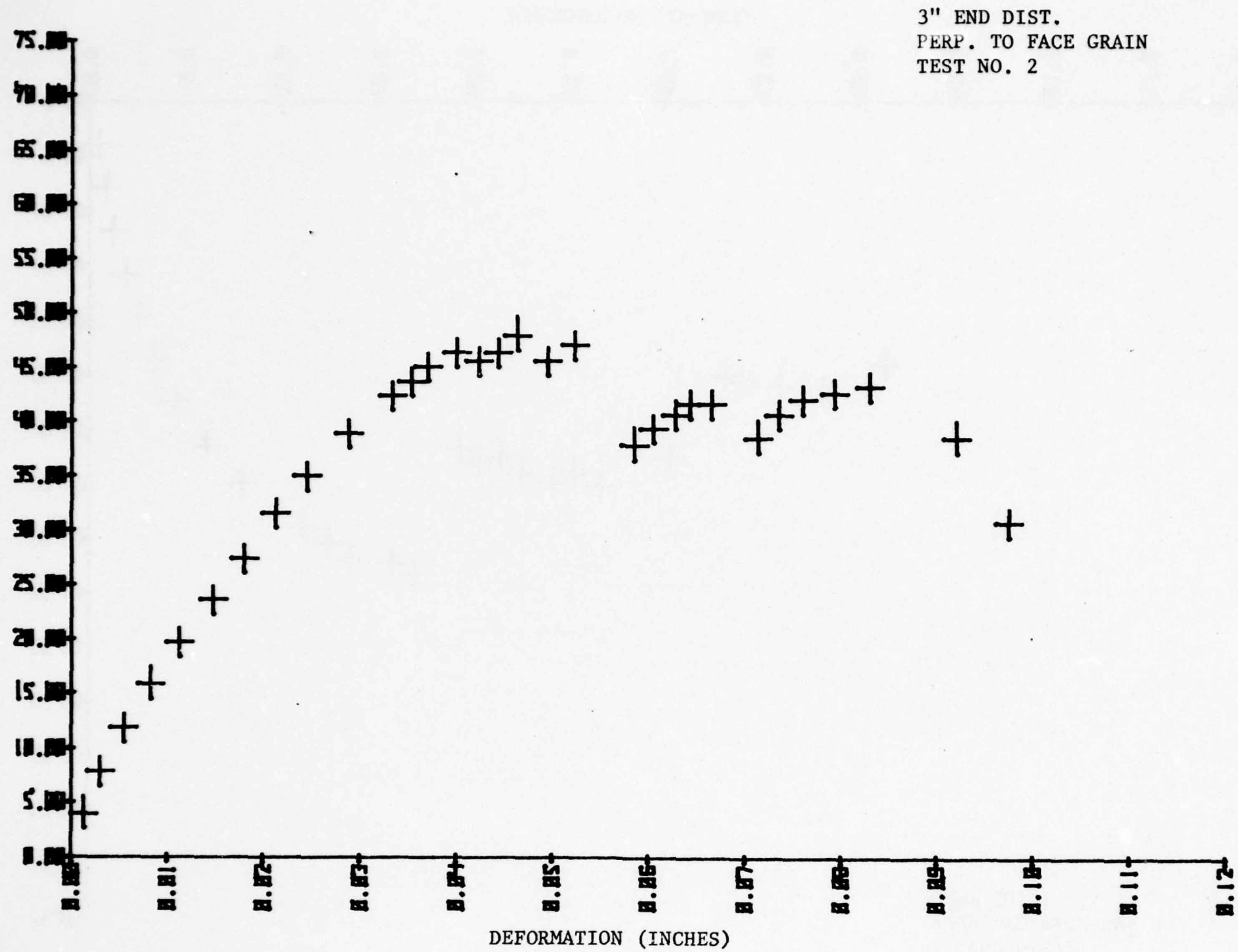
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)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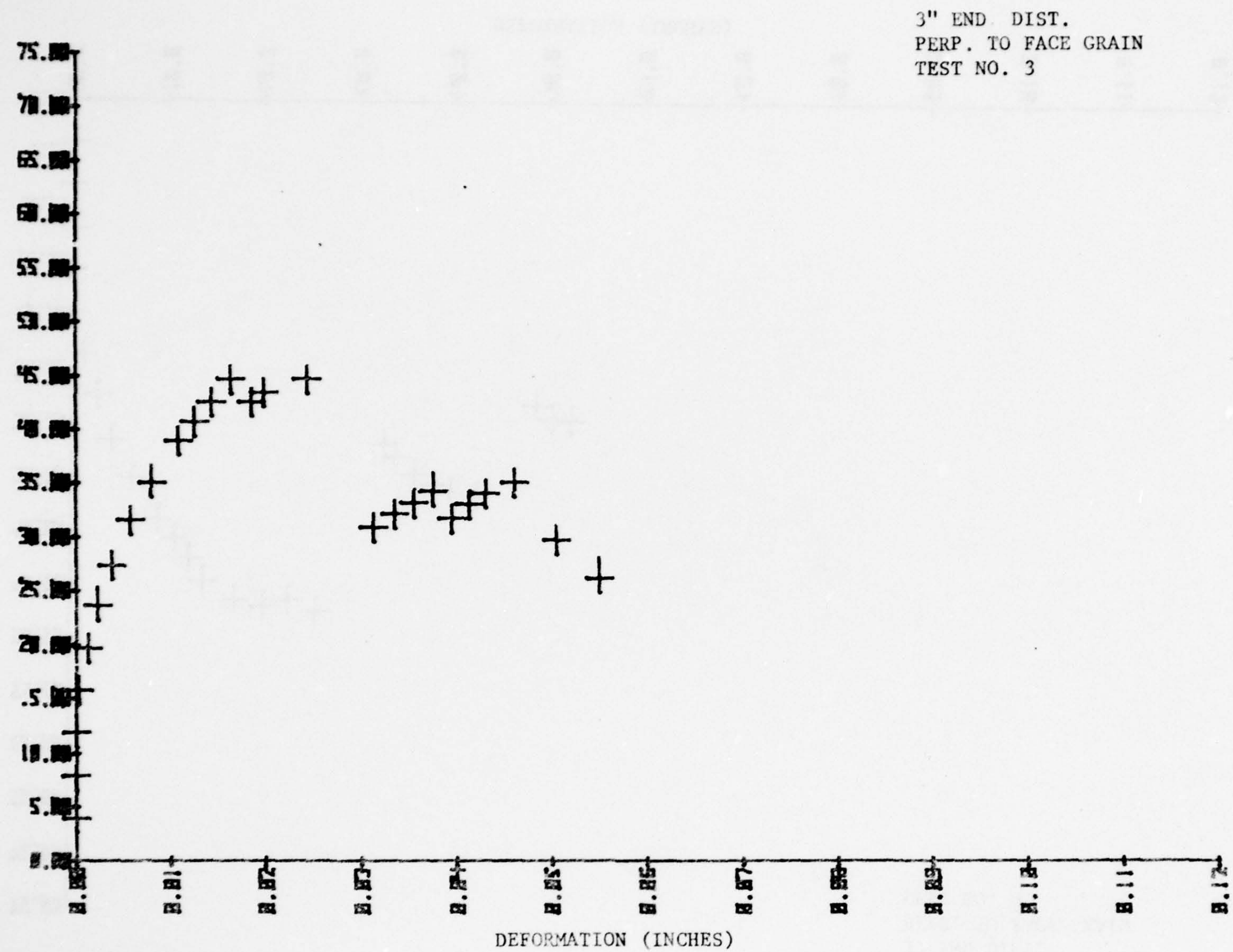
PERP. TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
DEFORMATION (INCHES)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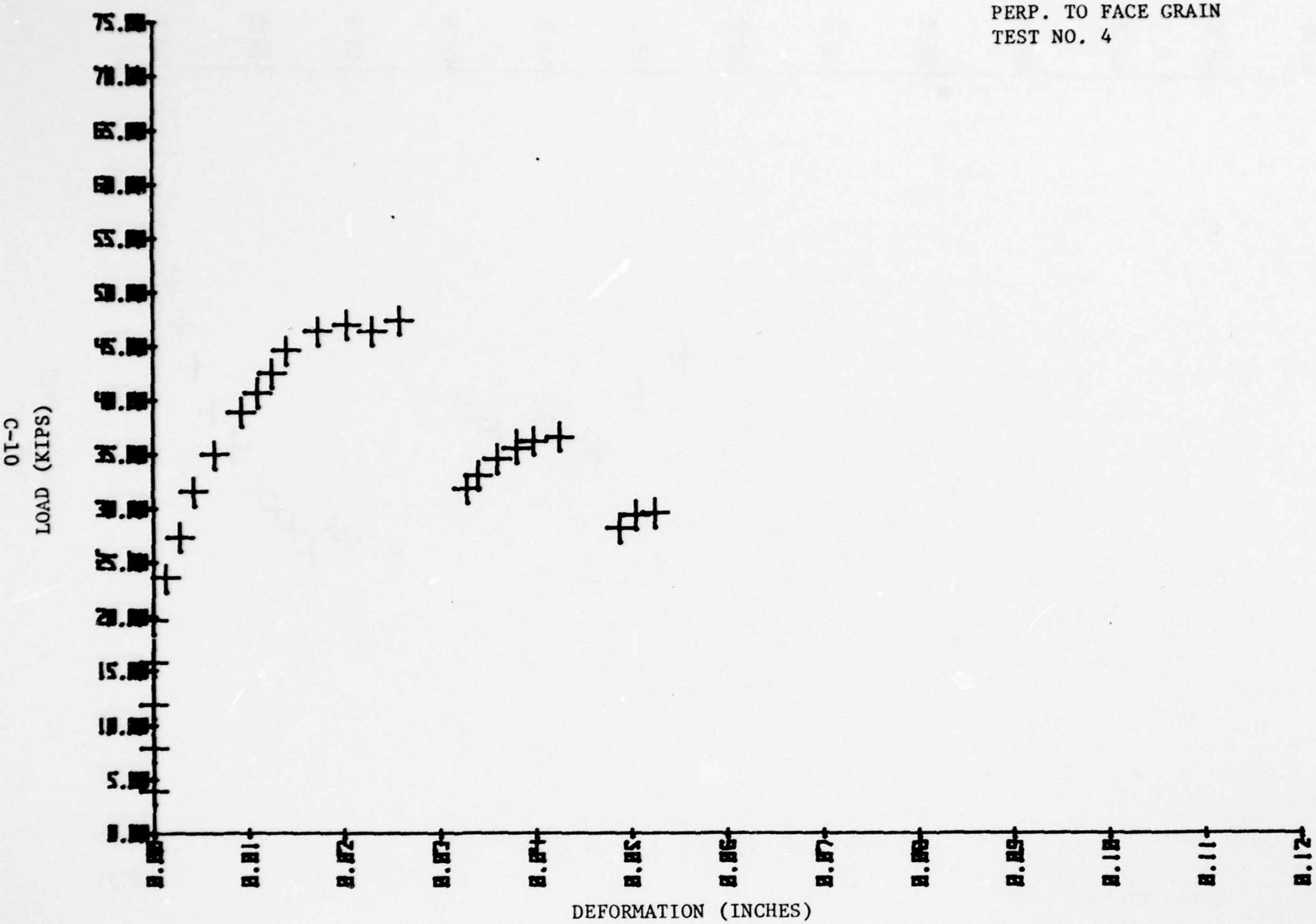
PERP. TO FACE GRAIN
TEST NO. 3
LOAD (KIPS)
DEFORMATION (INCHES)

3" END DIST.
PERP. TO FACE GRAIN
TEST NO. 4



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TEST AND EVALUATION OF SPLIT RING SHEAR CONNECTORS IN LAMINATED--ETC(U)
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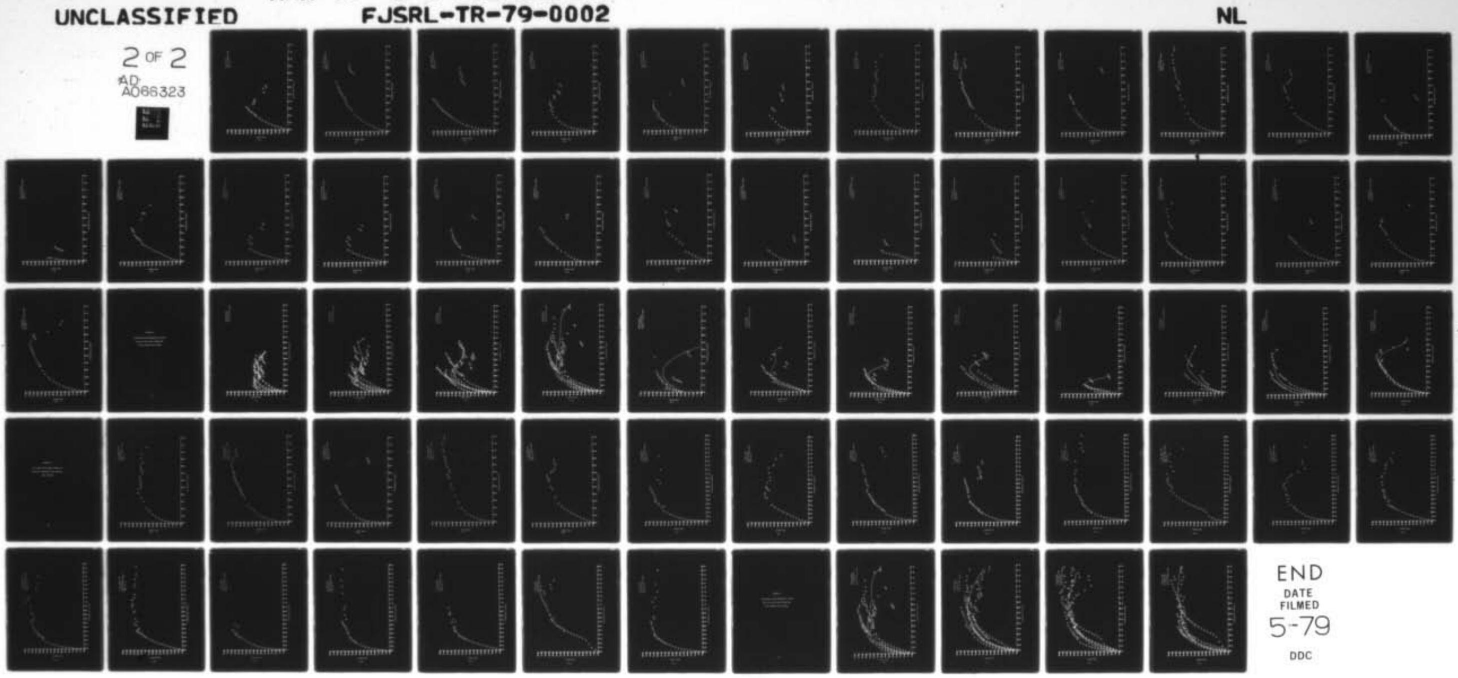

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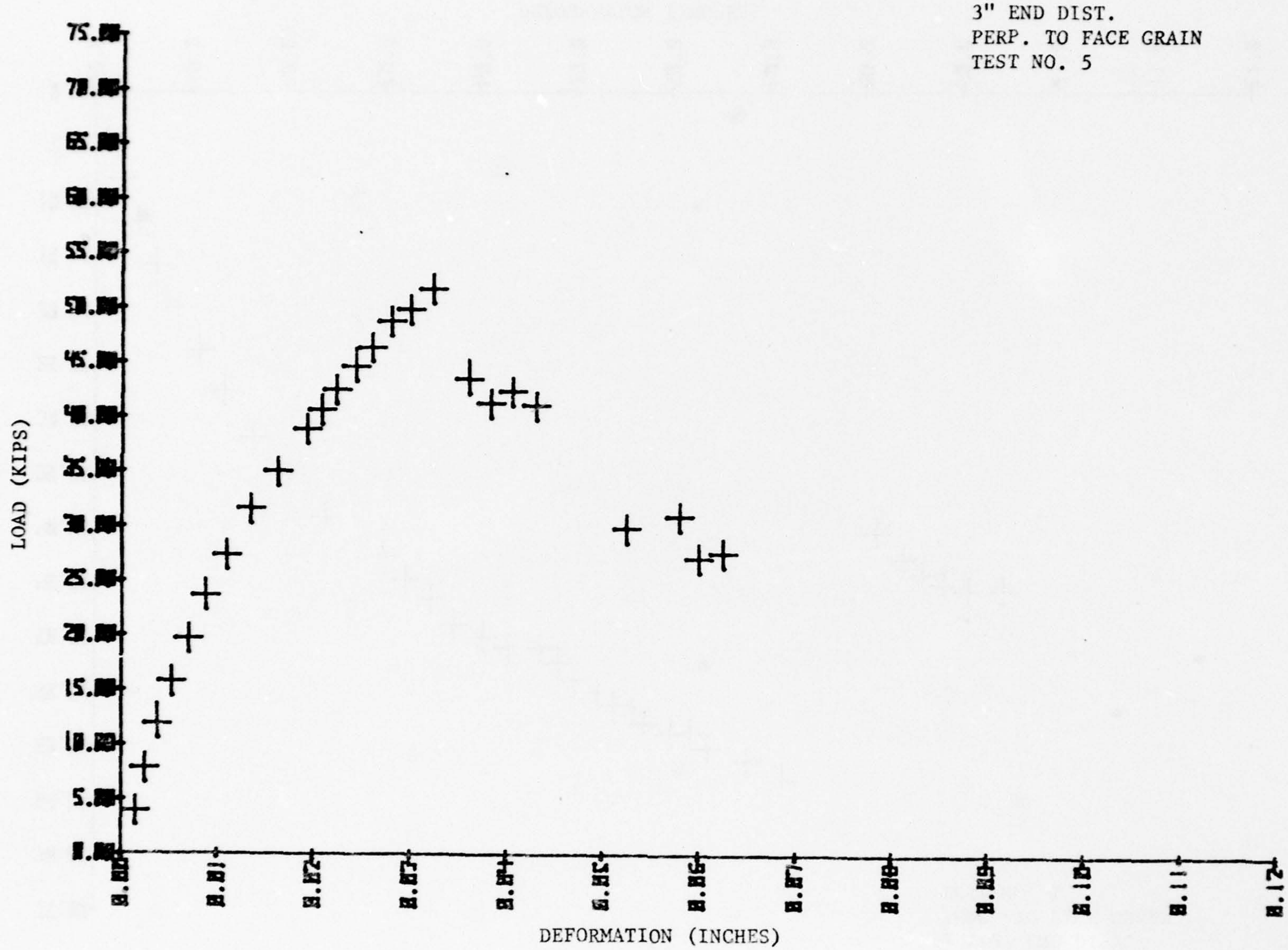
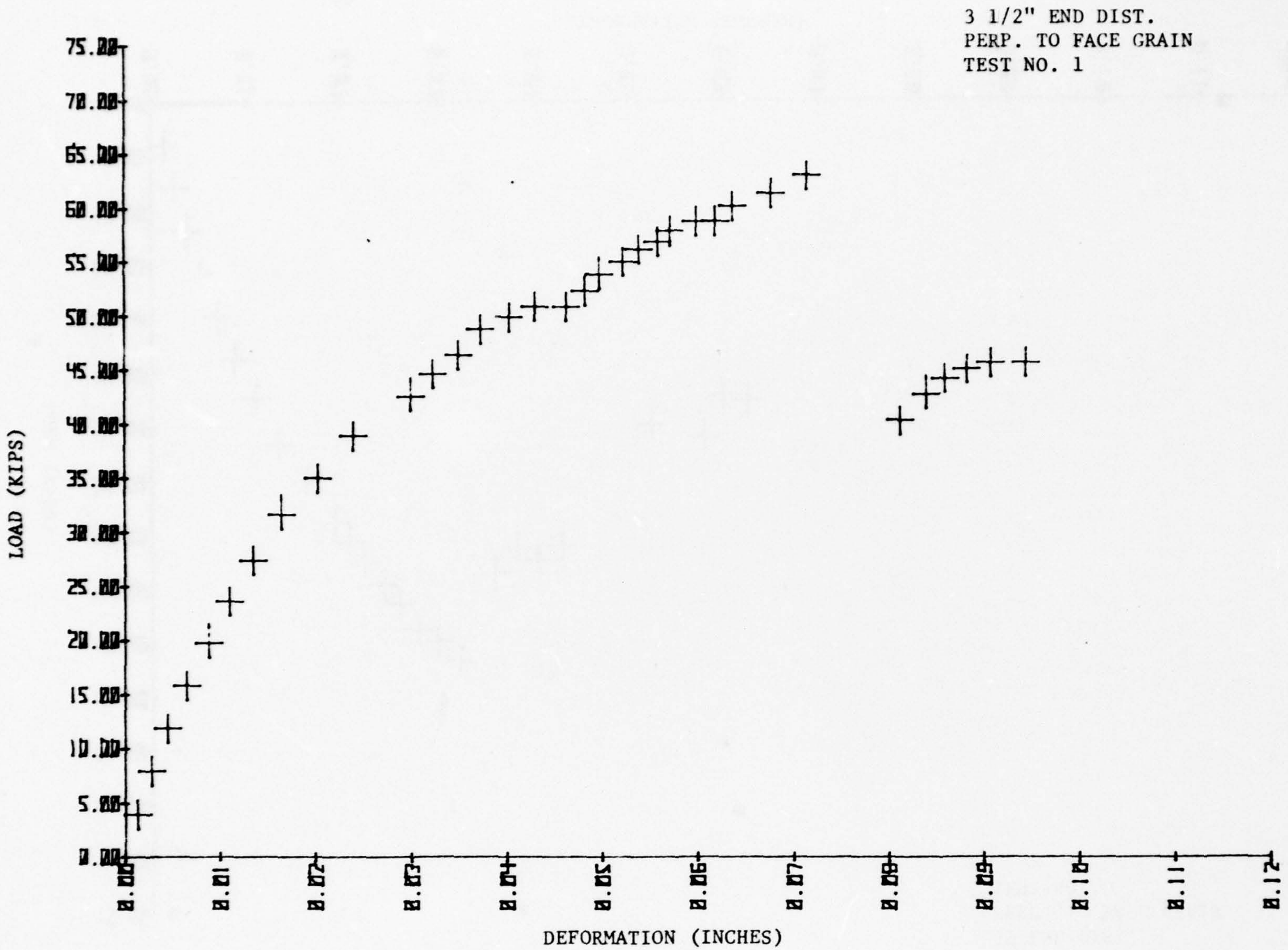
3" END DIST.
PERP. TO FACE GRAIN
TEST NO. 5

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PERP. TO FACE GRAIN
TEST NO. 1
LOAD (KIPS)
DEFORMATION (INCHES)
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5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
0.01
0.02
0.03
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0.05
0.06
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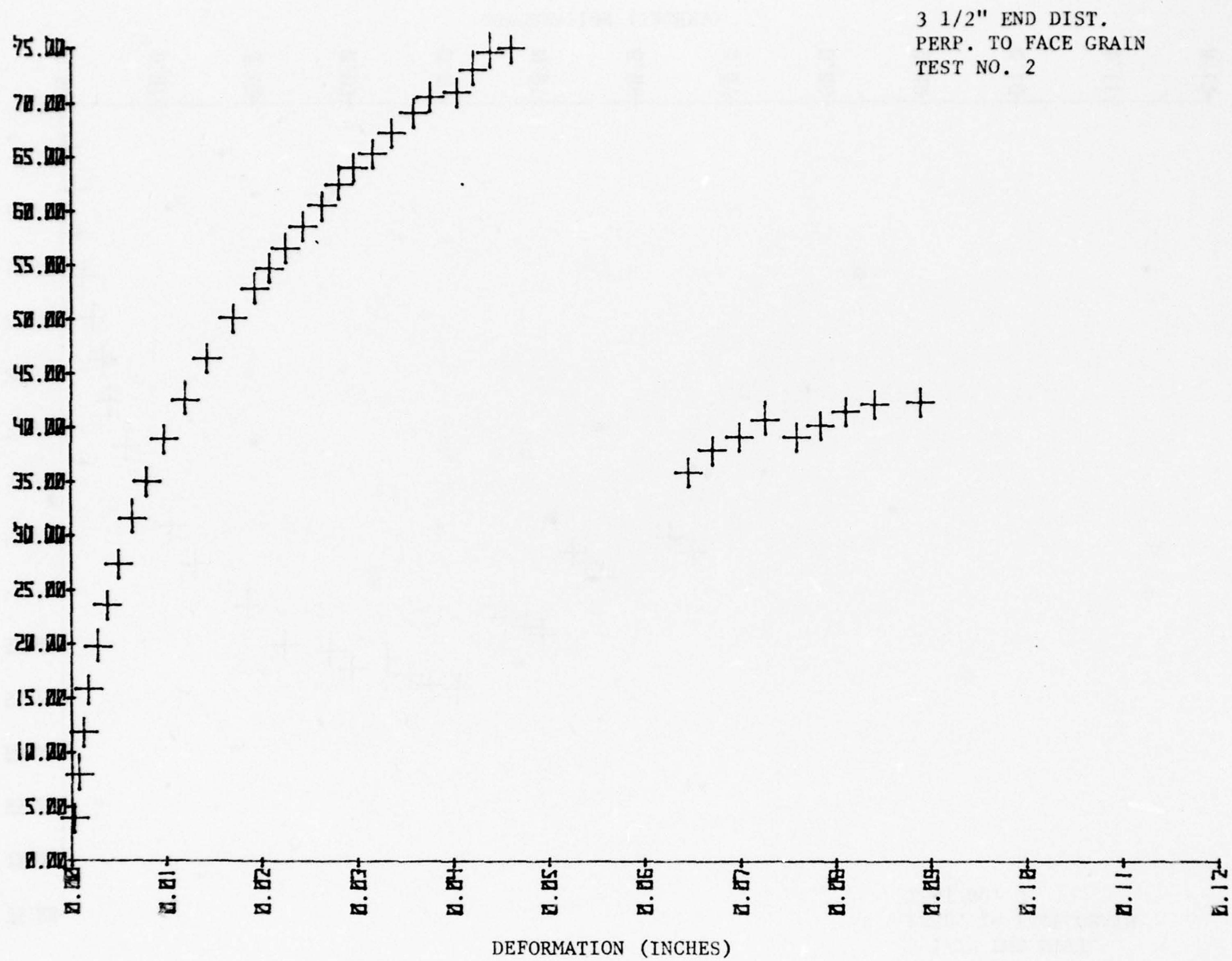
0.08
0.09
0.10
0.11
0.12



3 1/2" END DIST.
PERP. TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
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45.00
40.00
35.00
30.00
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10.00
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0.00
0.00
0.01
0.02
0.03
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0.07
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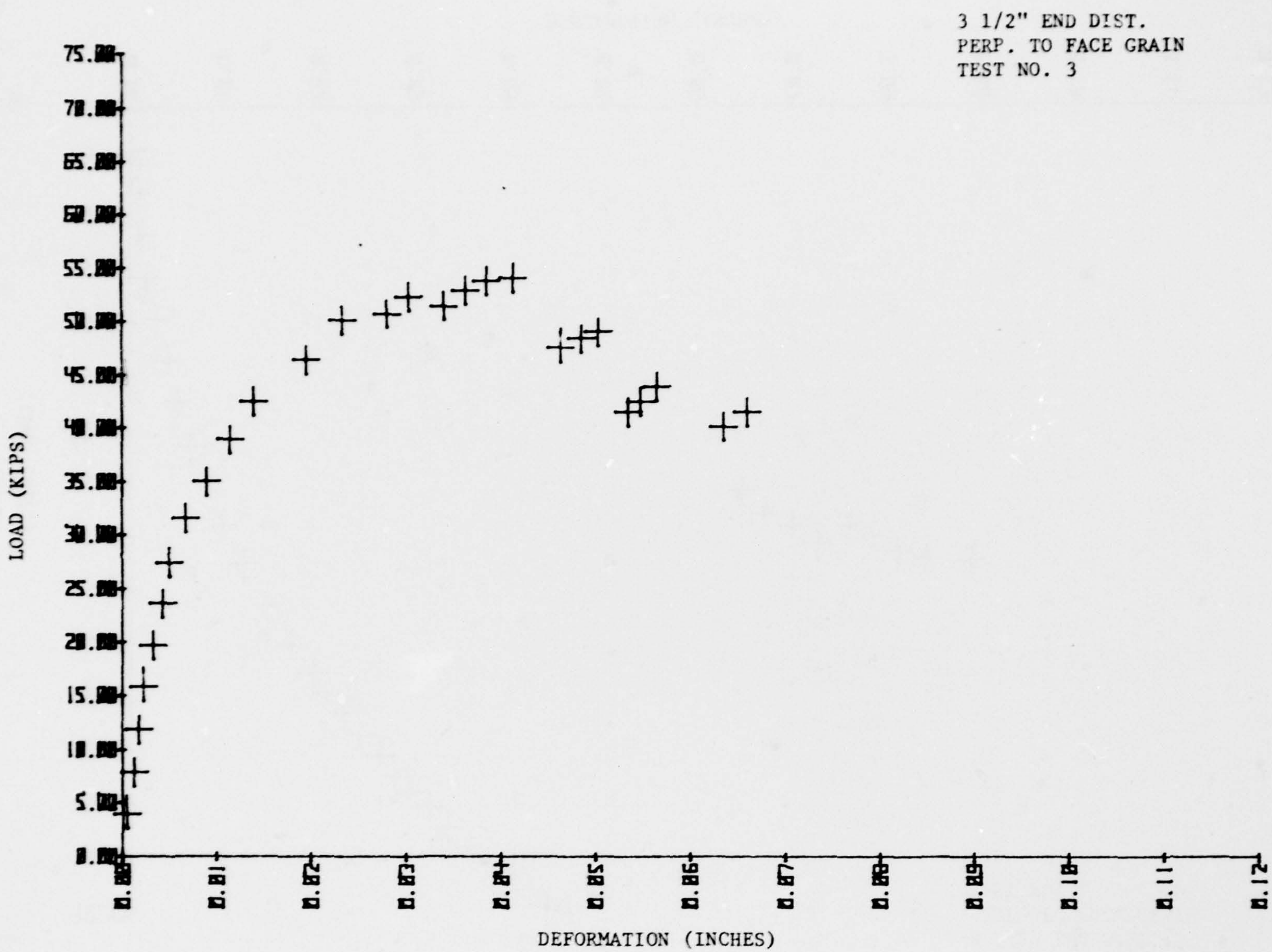
0.10
0.11
0.12
DEFORMATION (INCHES)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DEFORMATION (INCHES)
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5.00
0.00
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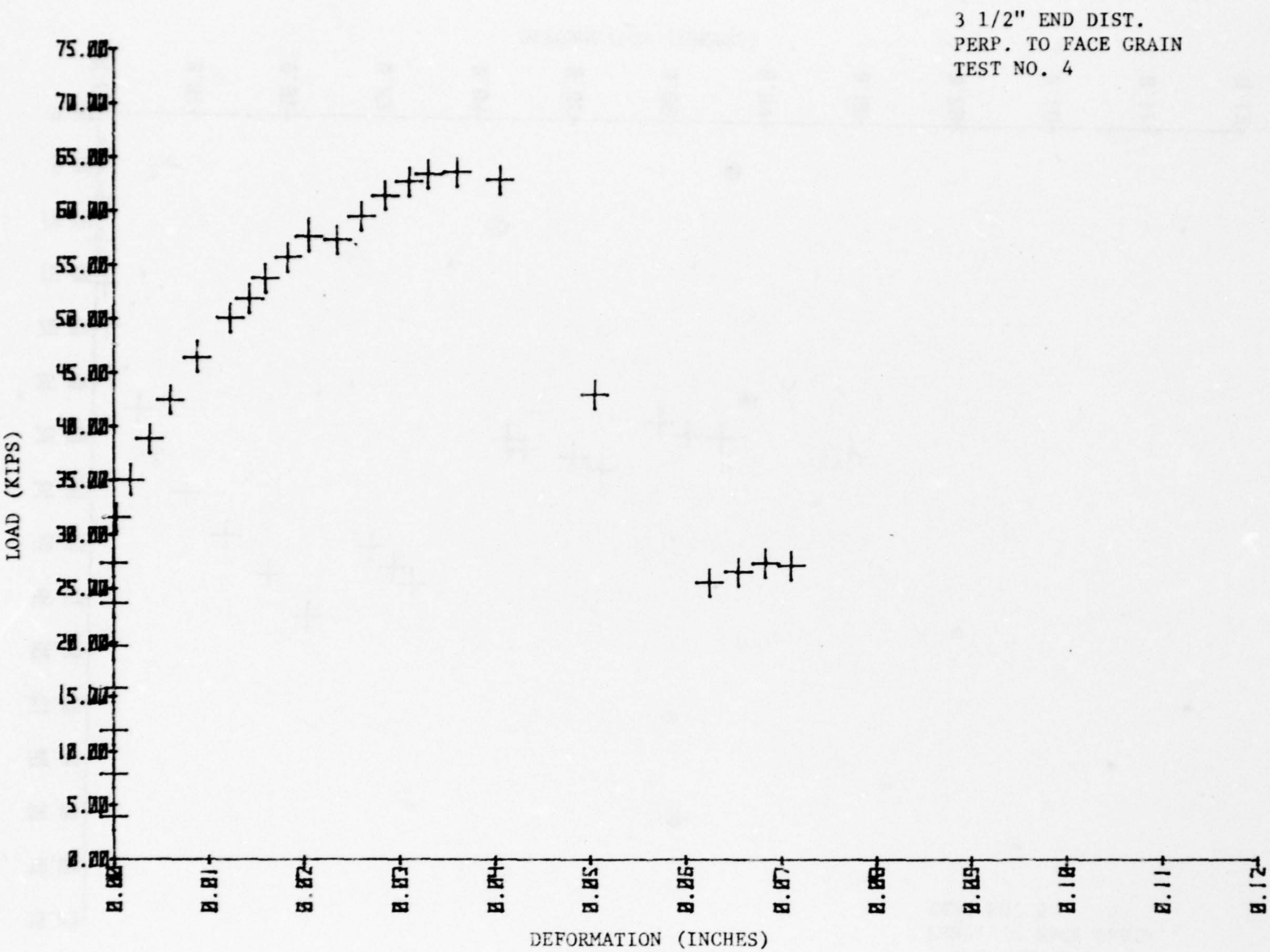
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10.00
5.00
0.00
0.00
0.01
0.02
0.03
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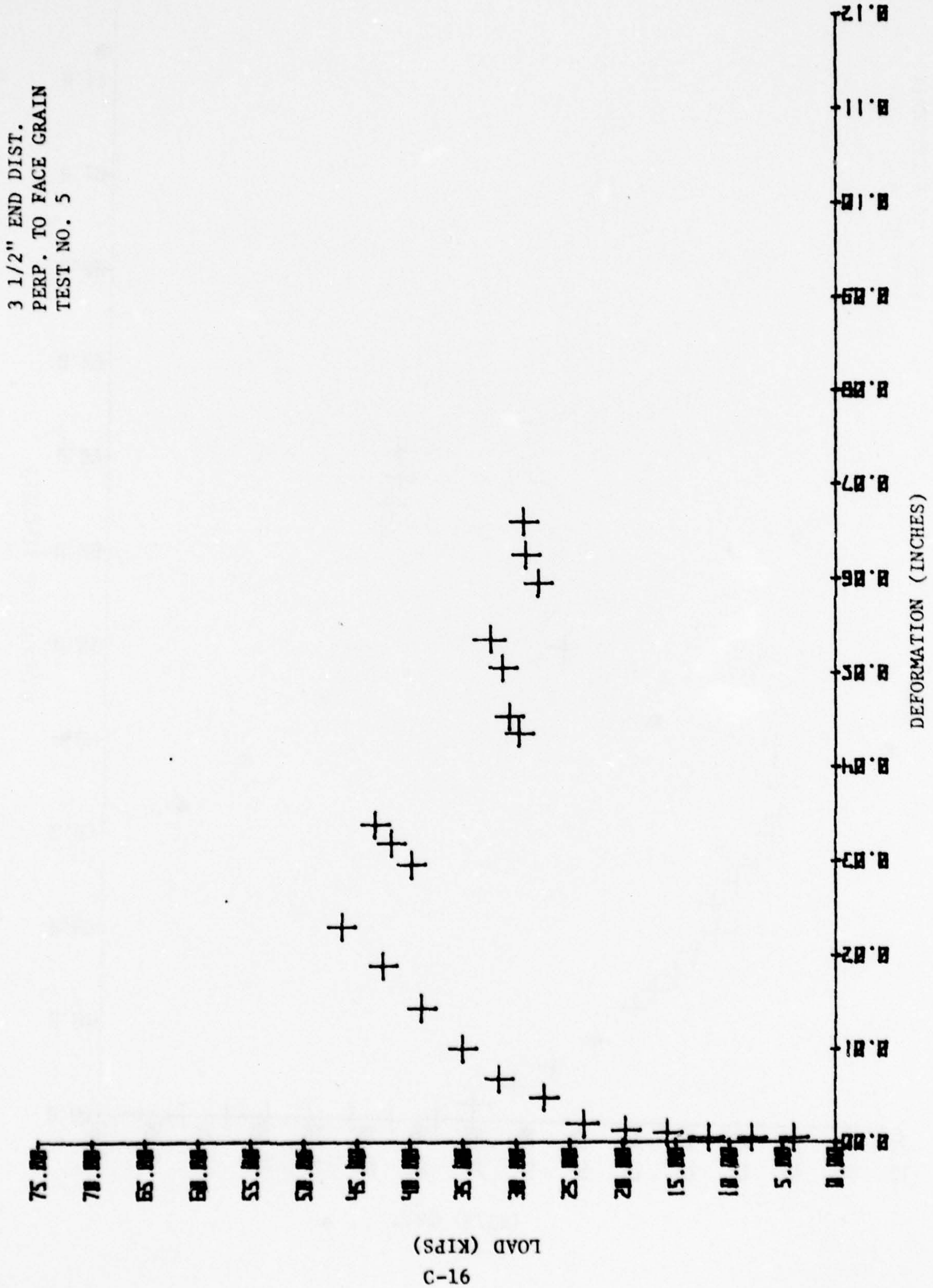
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)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PERP. TO FACE GRAIN
TEST NO. 5
DEFORMATION (INCHES)
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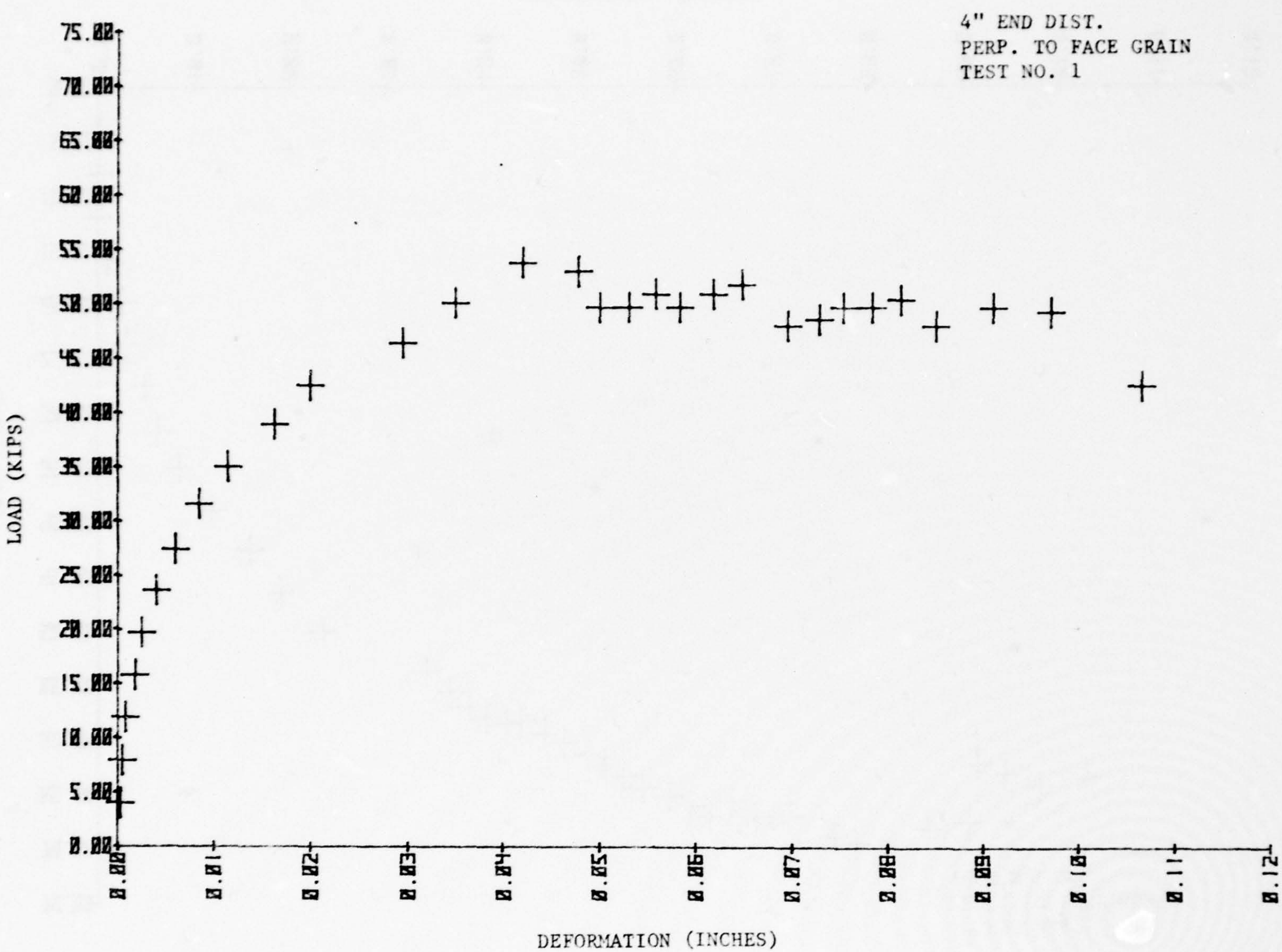
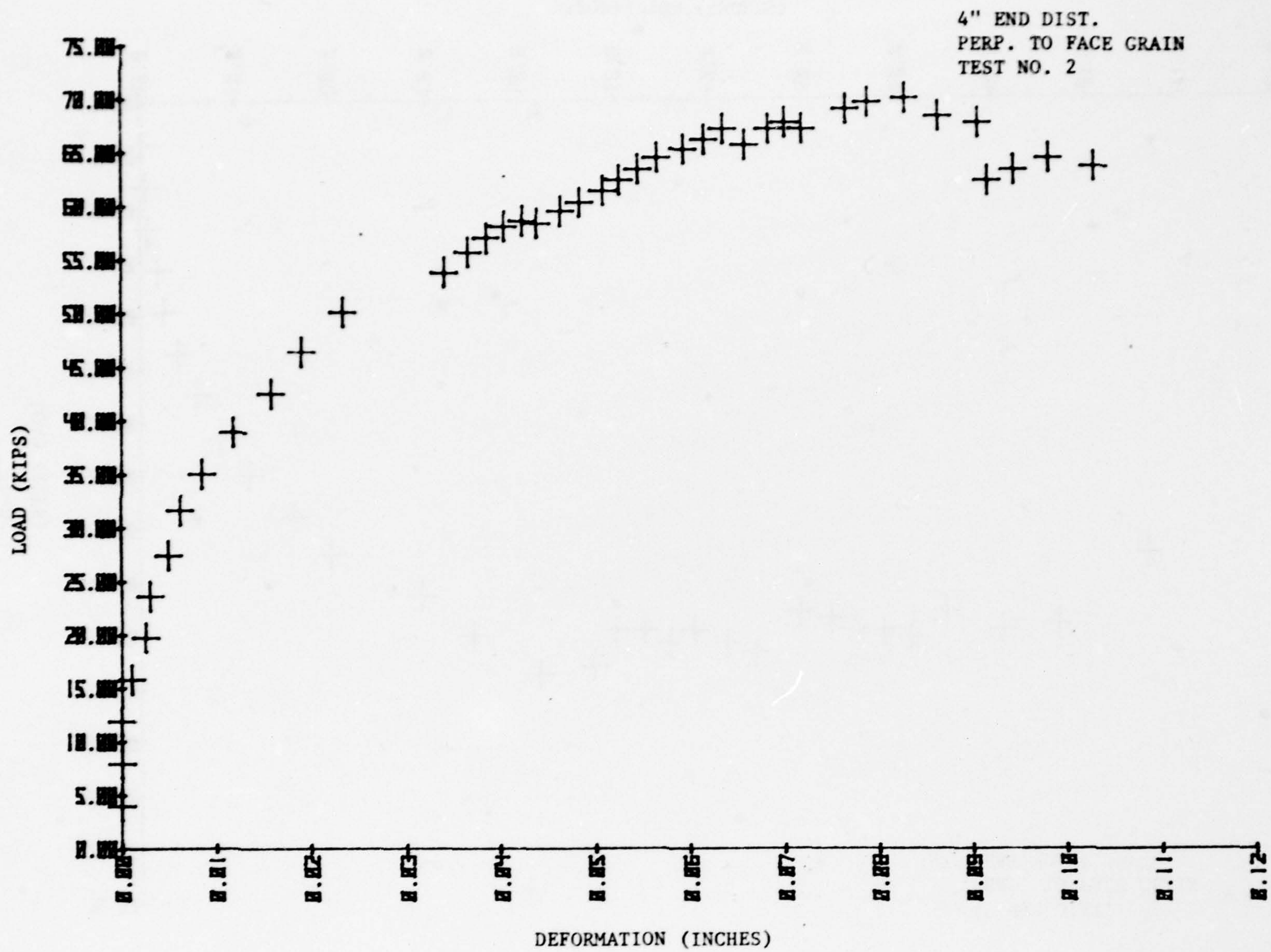
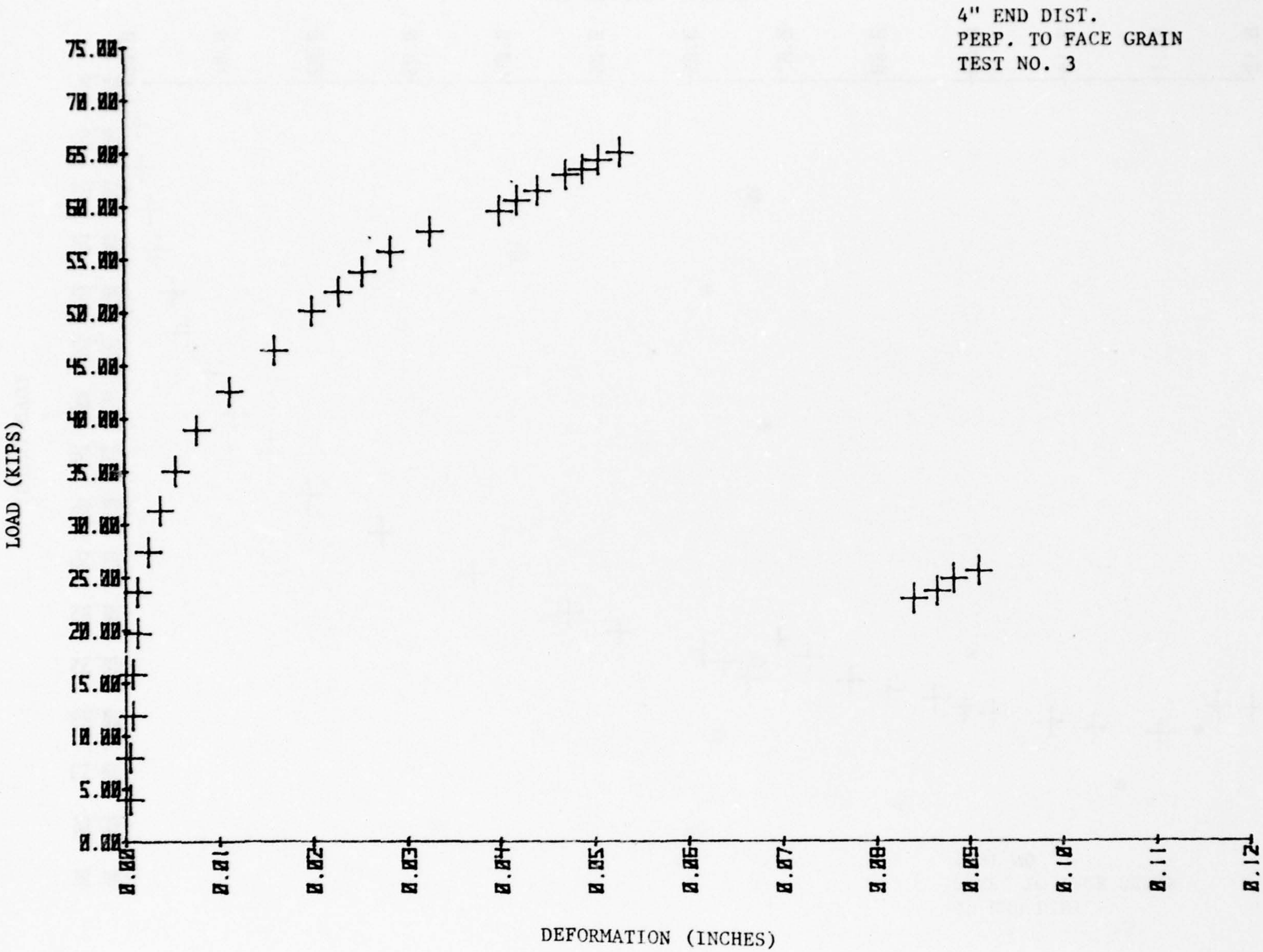
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00


4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 1
LOAD (KIPS)
DEFORMATION (INCHES)
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12


4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
DEFORMATION (INCHES)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12


4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 3
LOAD (KIPS)
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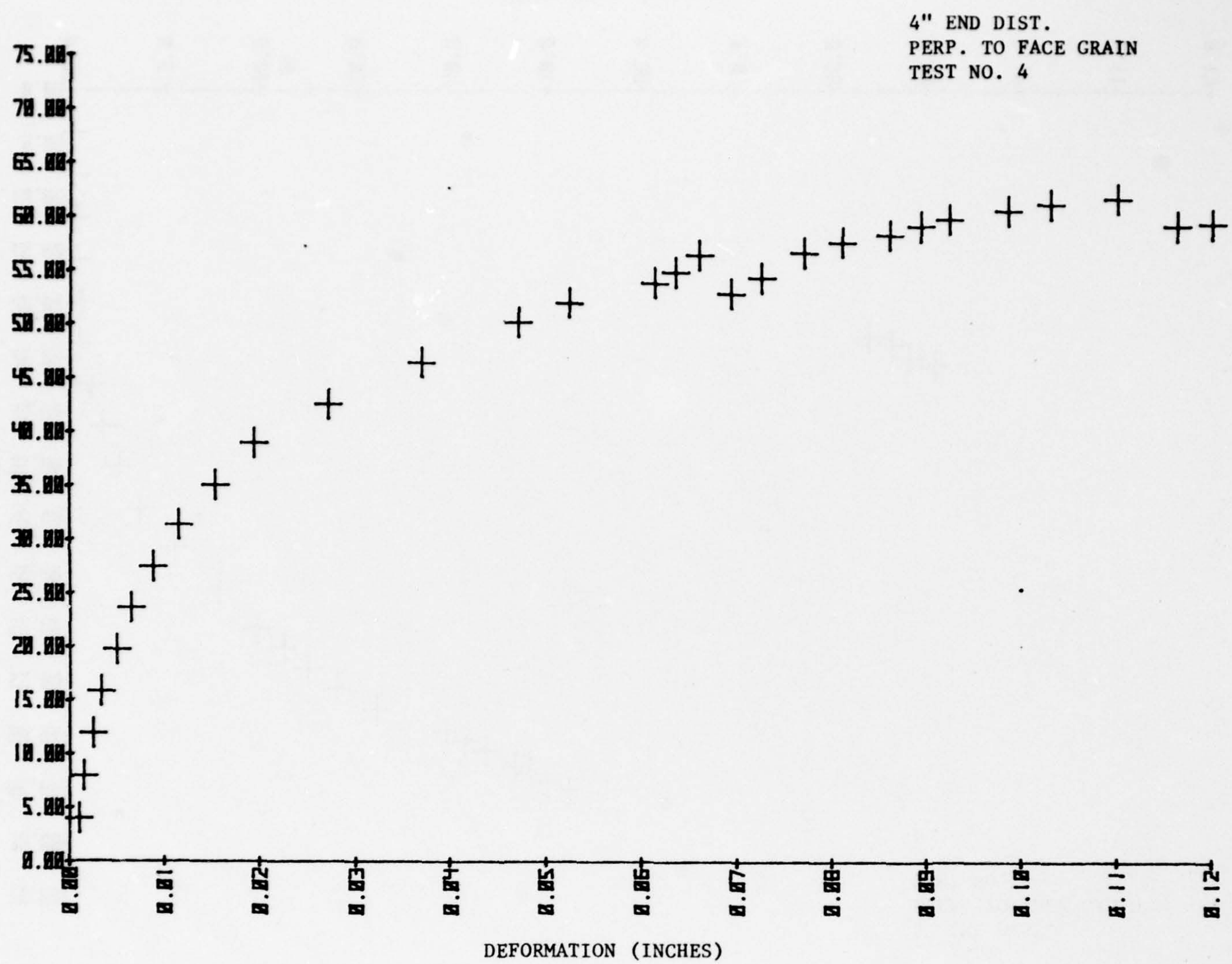
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)


4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 4
LOAD (KIPS)
DEFORMATION (INCHES)
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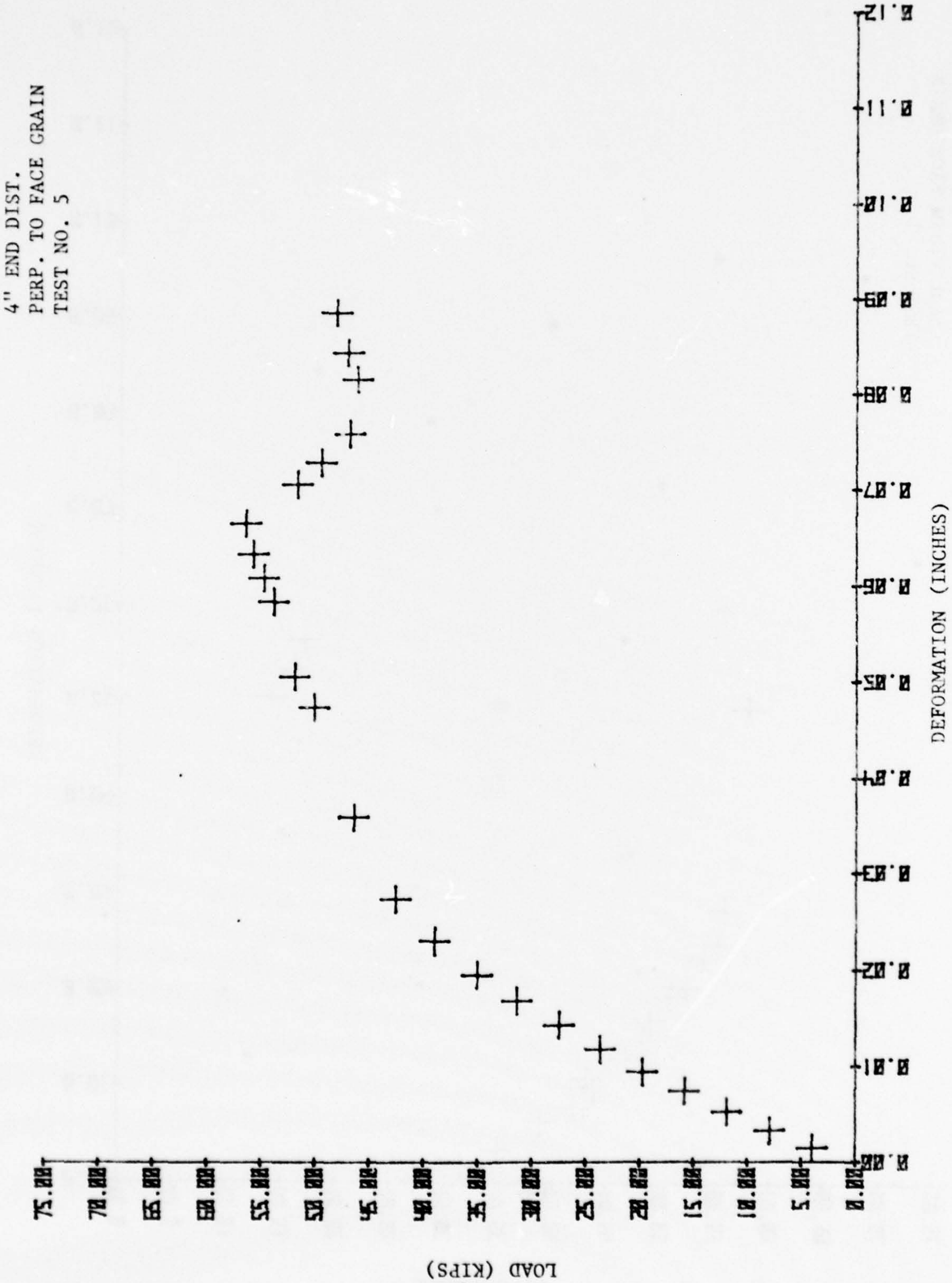
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12



4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 5
DEFORMATION (INCHES)
LOAD (KIPS)
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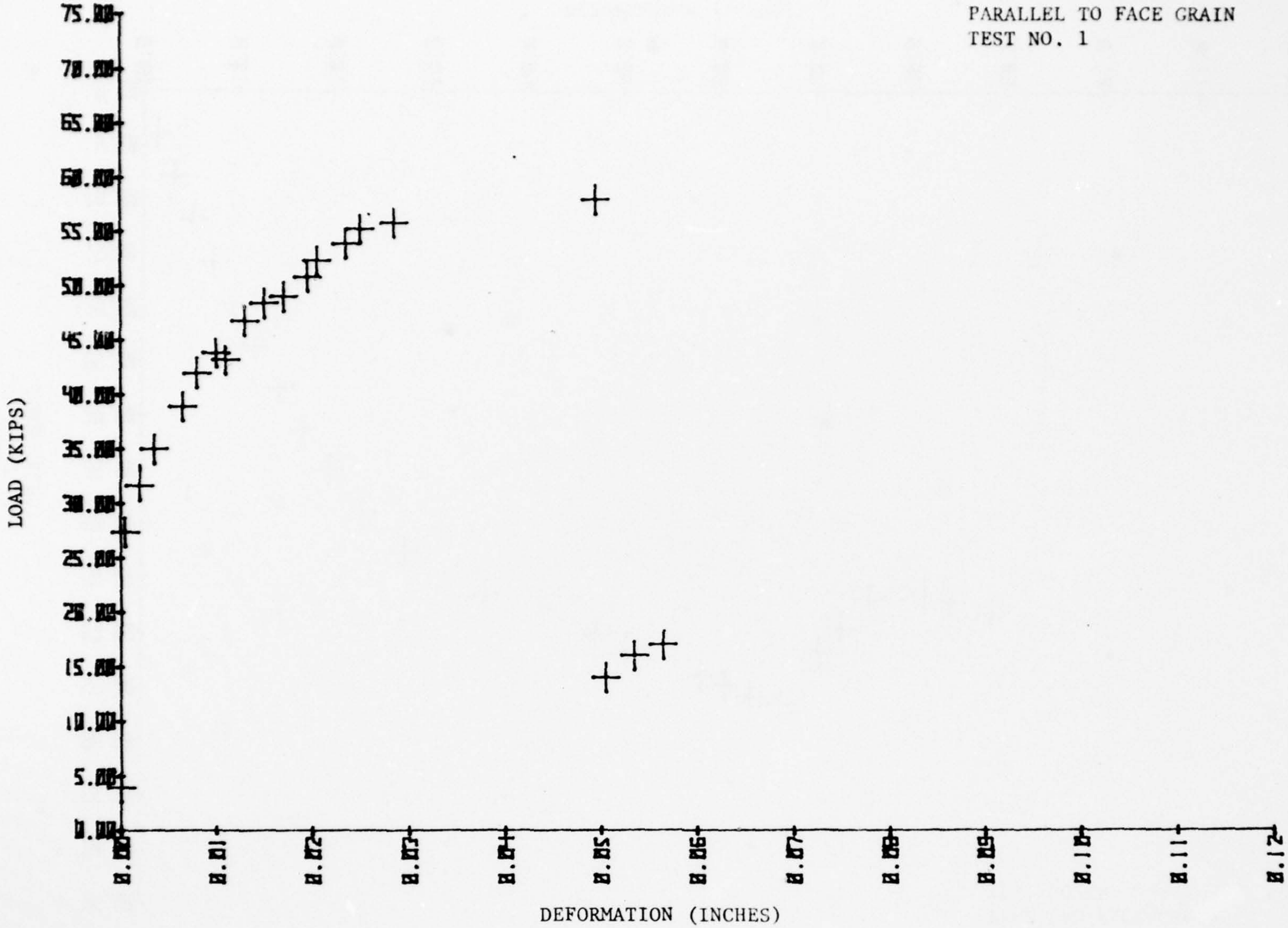
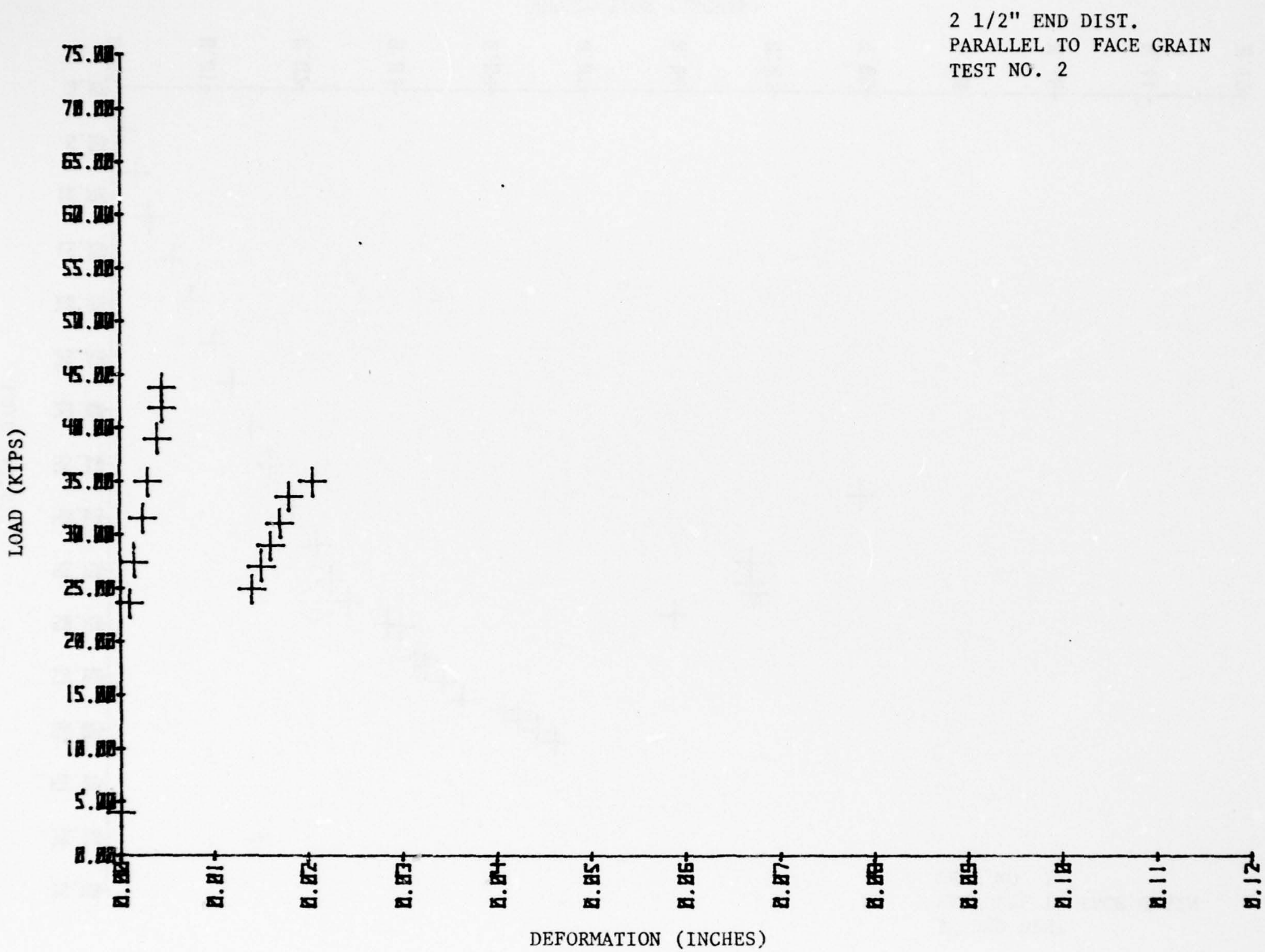
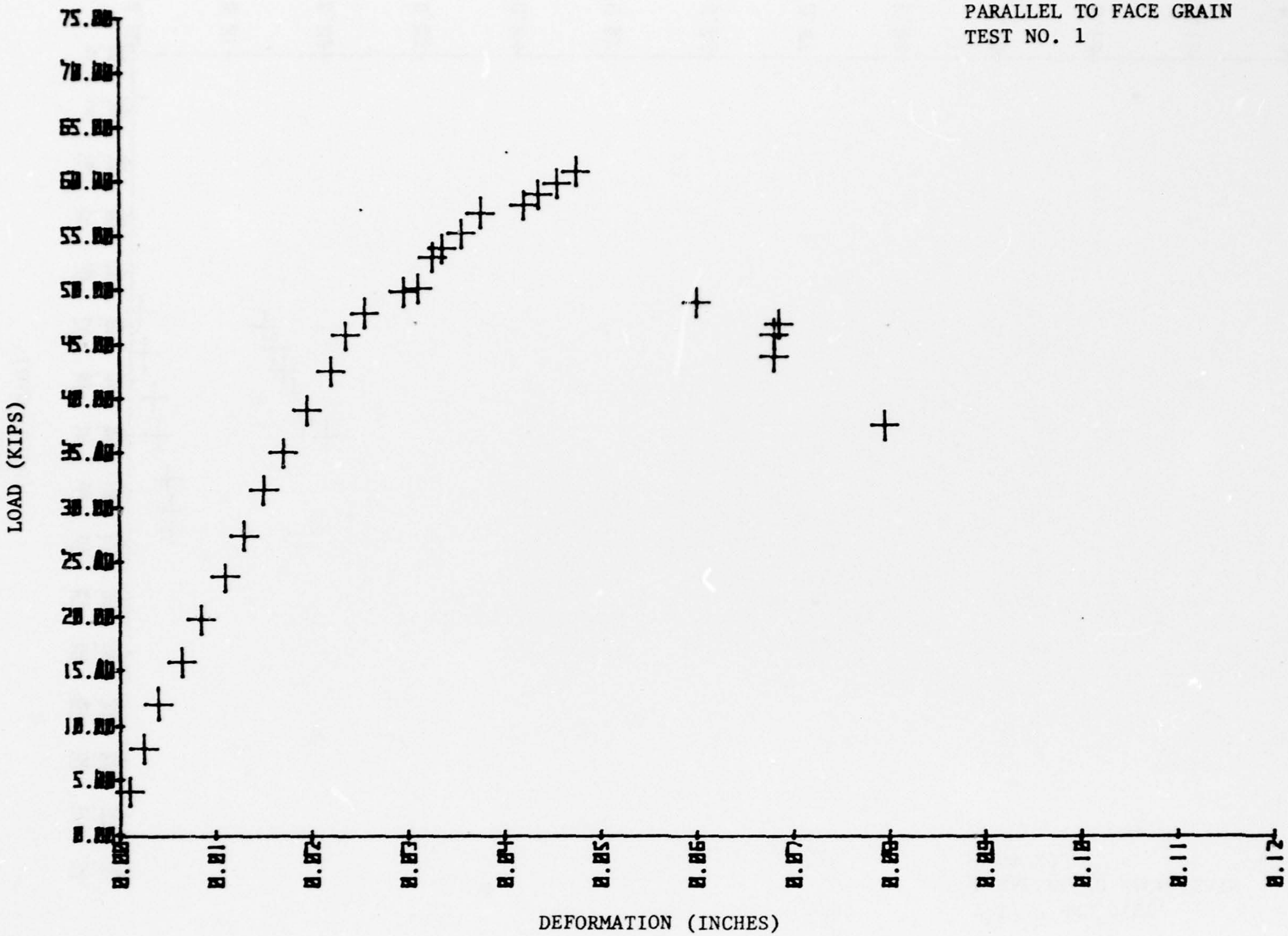
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00

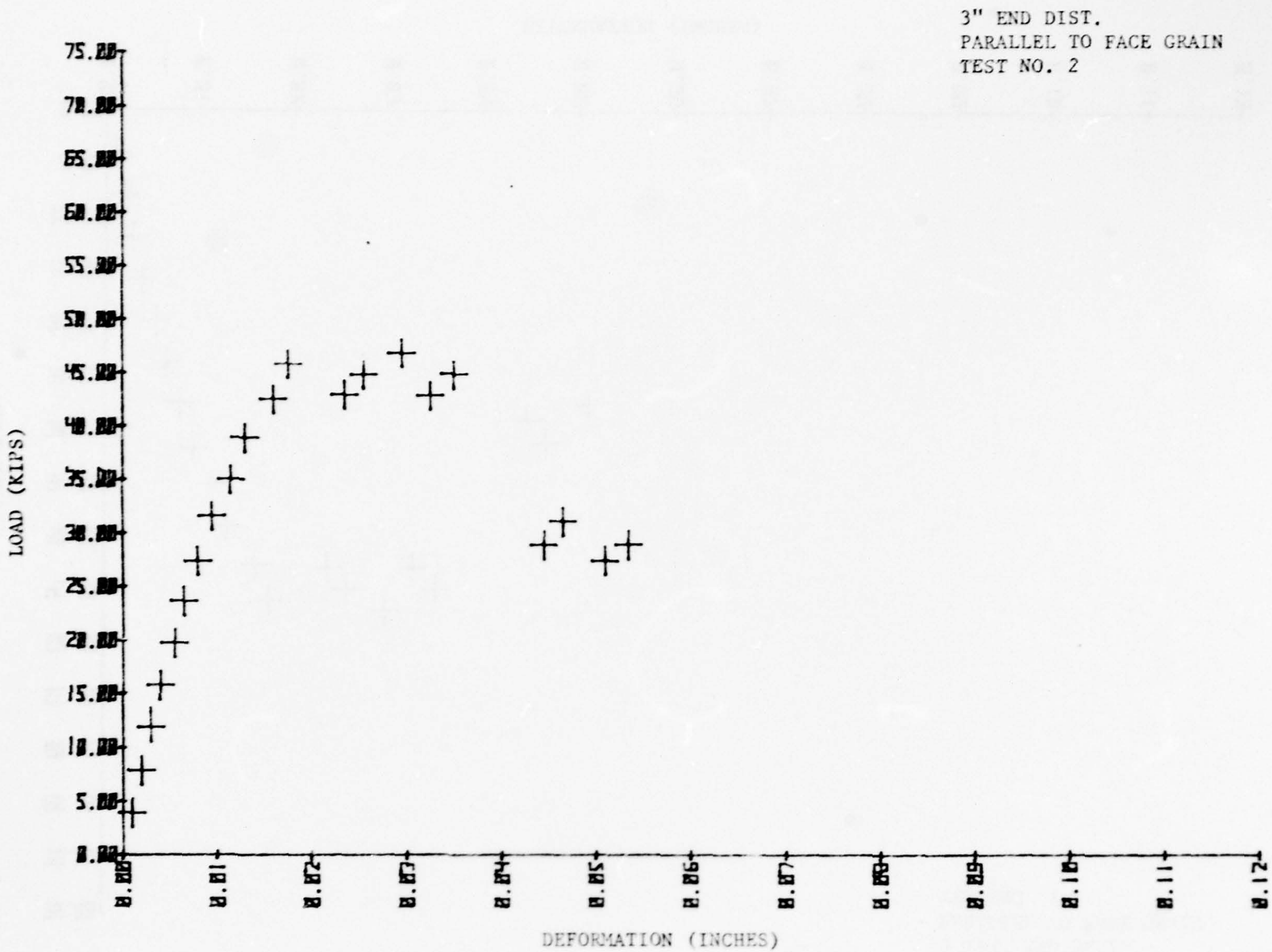
2 1/2" END DIST.
PARALLEL TO FACE GRAIN
TEST NO. 1



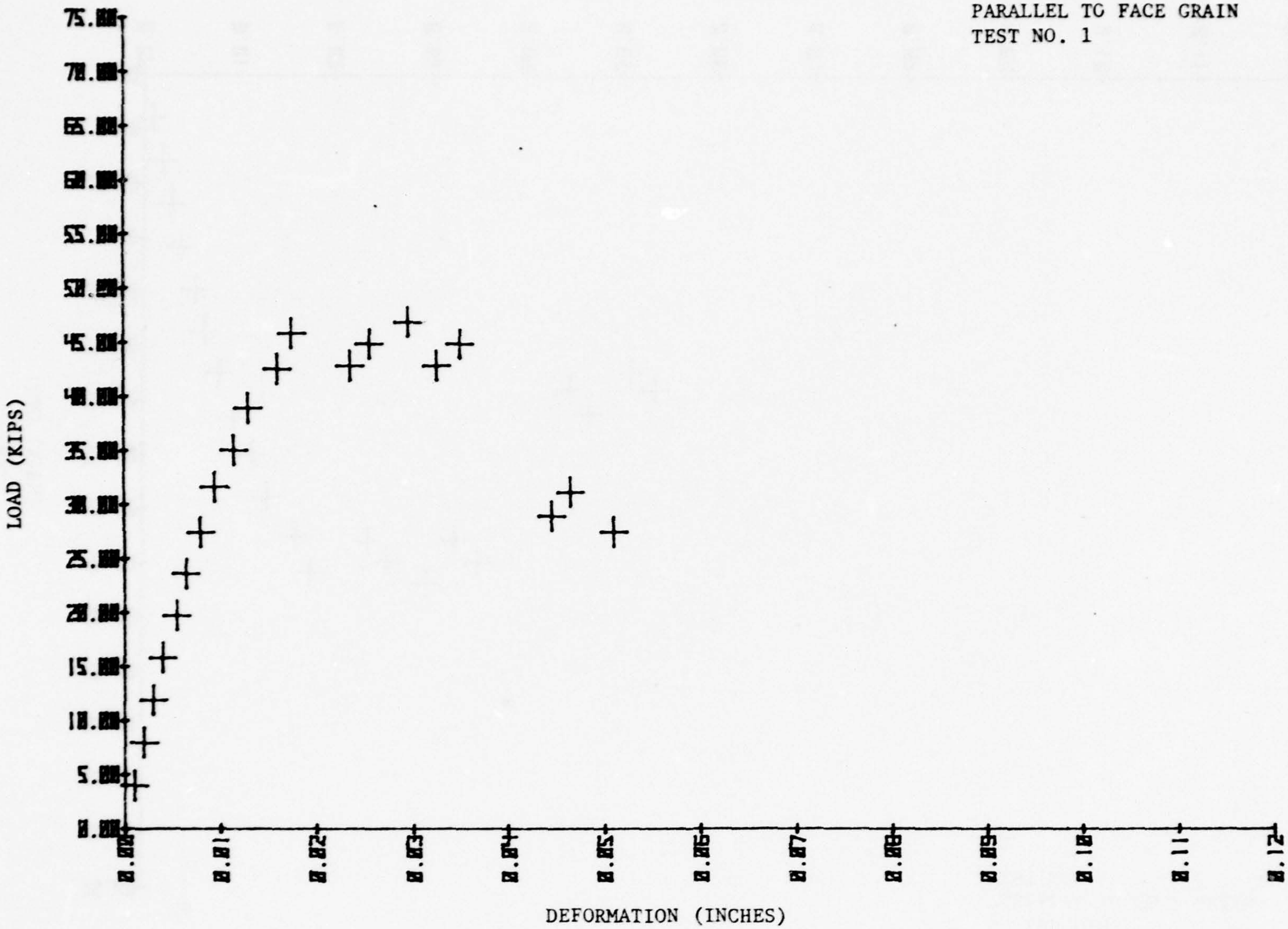

2 1/2" END DIST.
PARALLEL TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
DEFORMATION (INCHES)

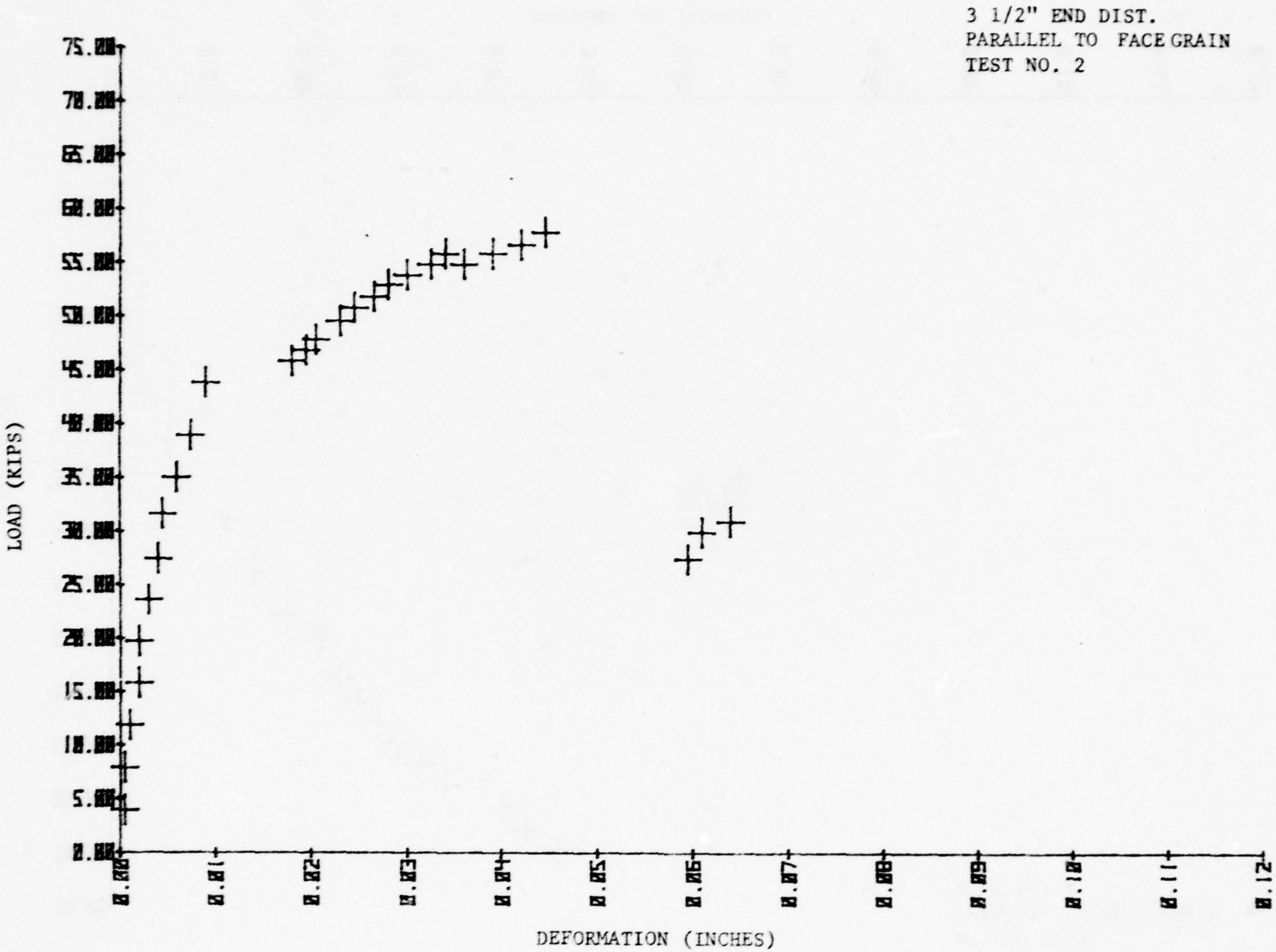
3" END DIST.
PARALLEL TO FACE GRAIN
TEST NO. 1




3" END DIST.
PARALLEL TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
DEFORMATION (INCHES)

3 1/2" END DIST.
PARALLEL TO FACE GRAIN
TEST NO. 1





3 1/2" END DIST.
PARALLEL TO FACE GRAIN
TEST NO. 2
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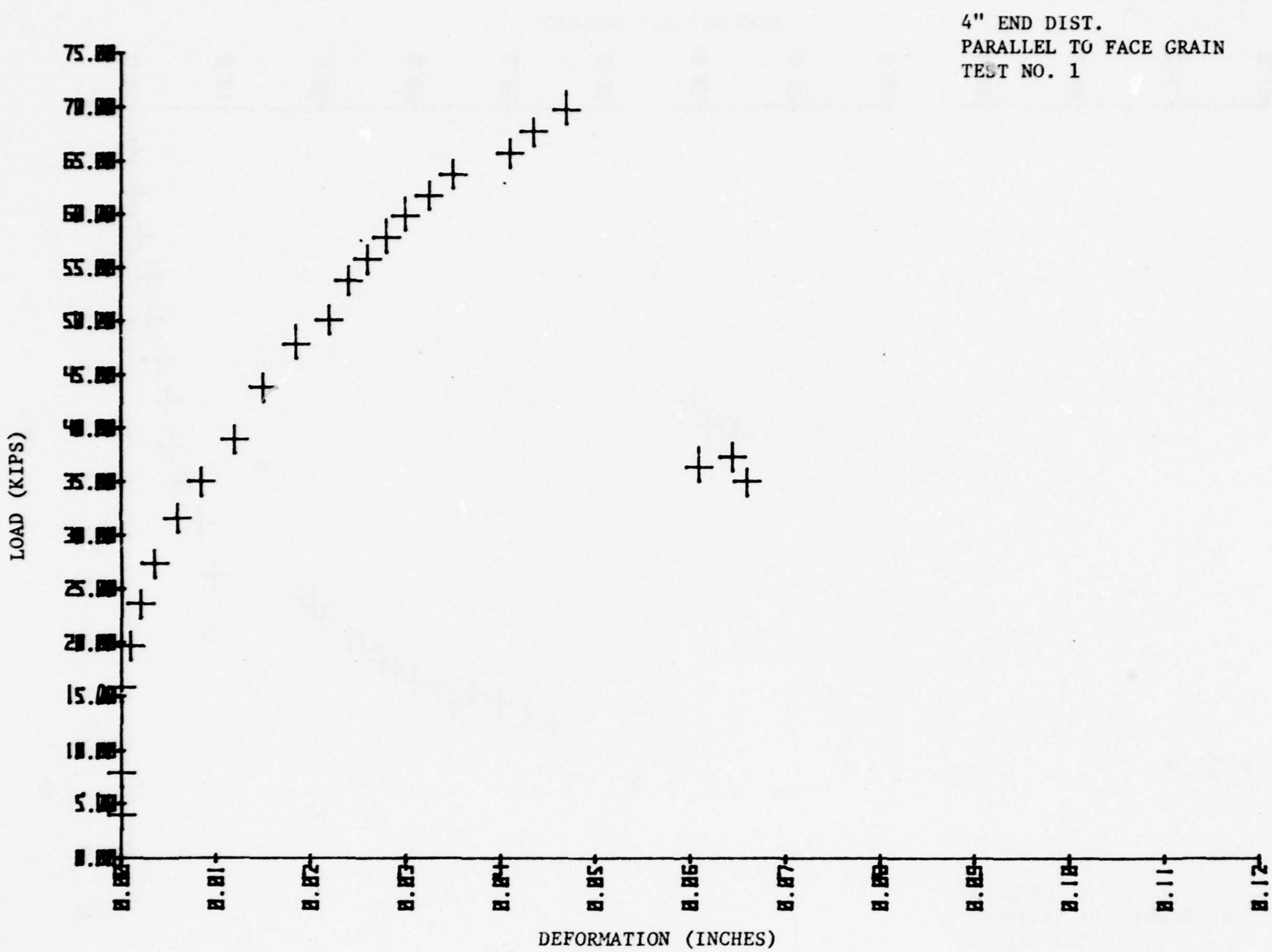
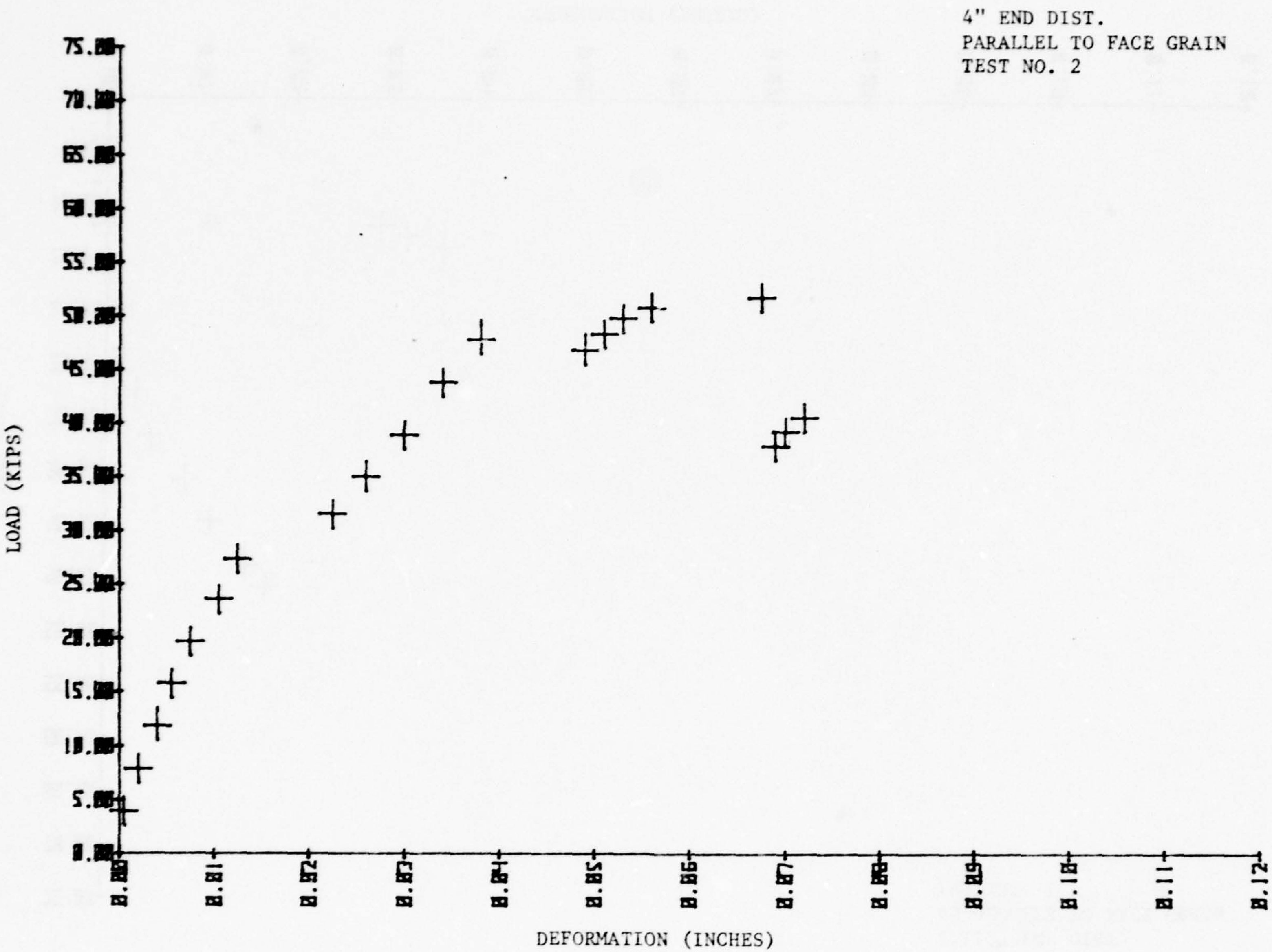
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)


4" END DIST.
PARALLEL TO FACE GRAIN
TEST NO. 1
LOAD (KIPS)
DEFORMATION (INCHES)


4" END DIST.
PARALLEL TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
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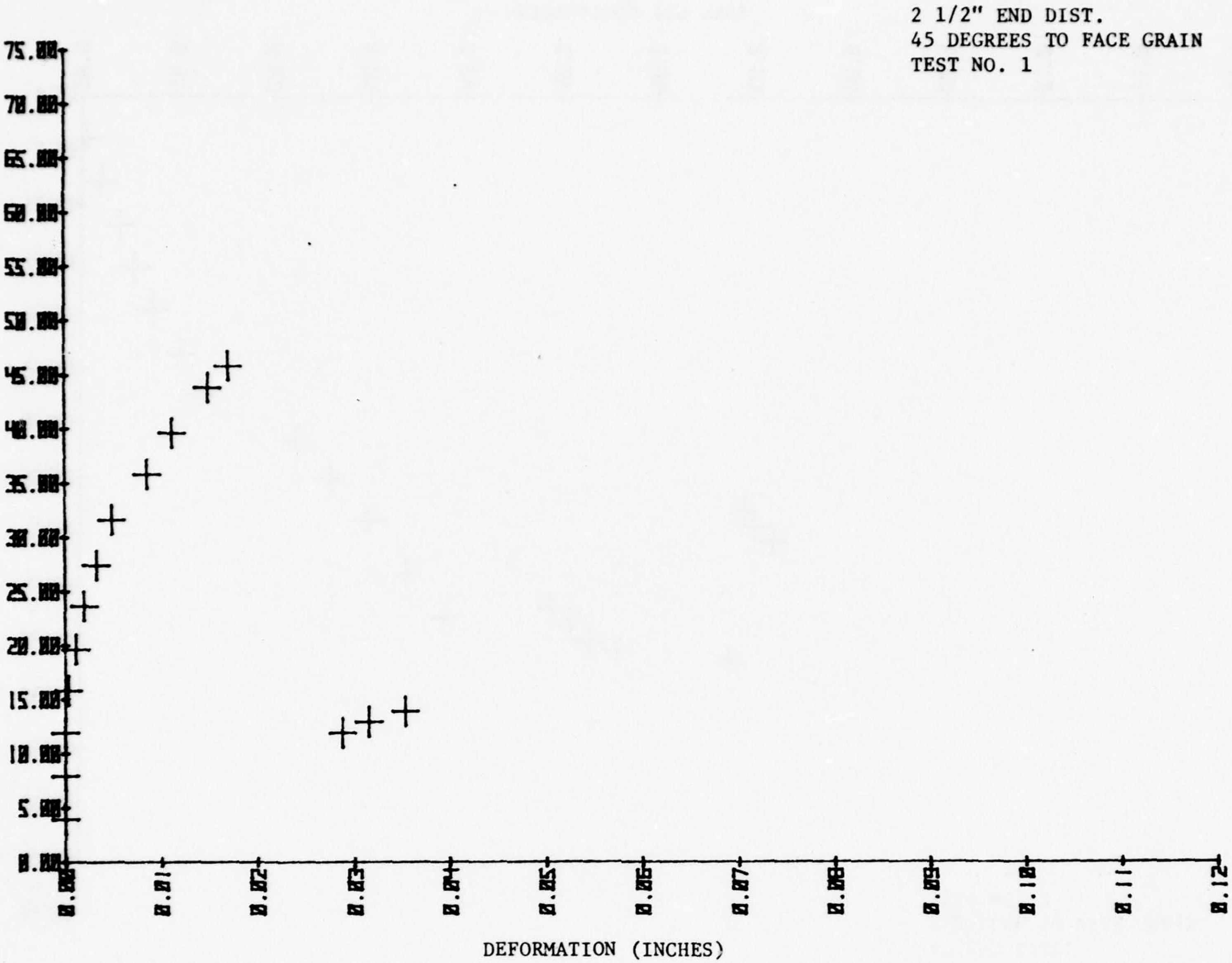
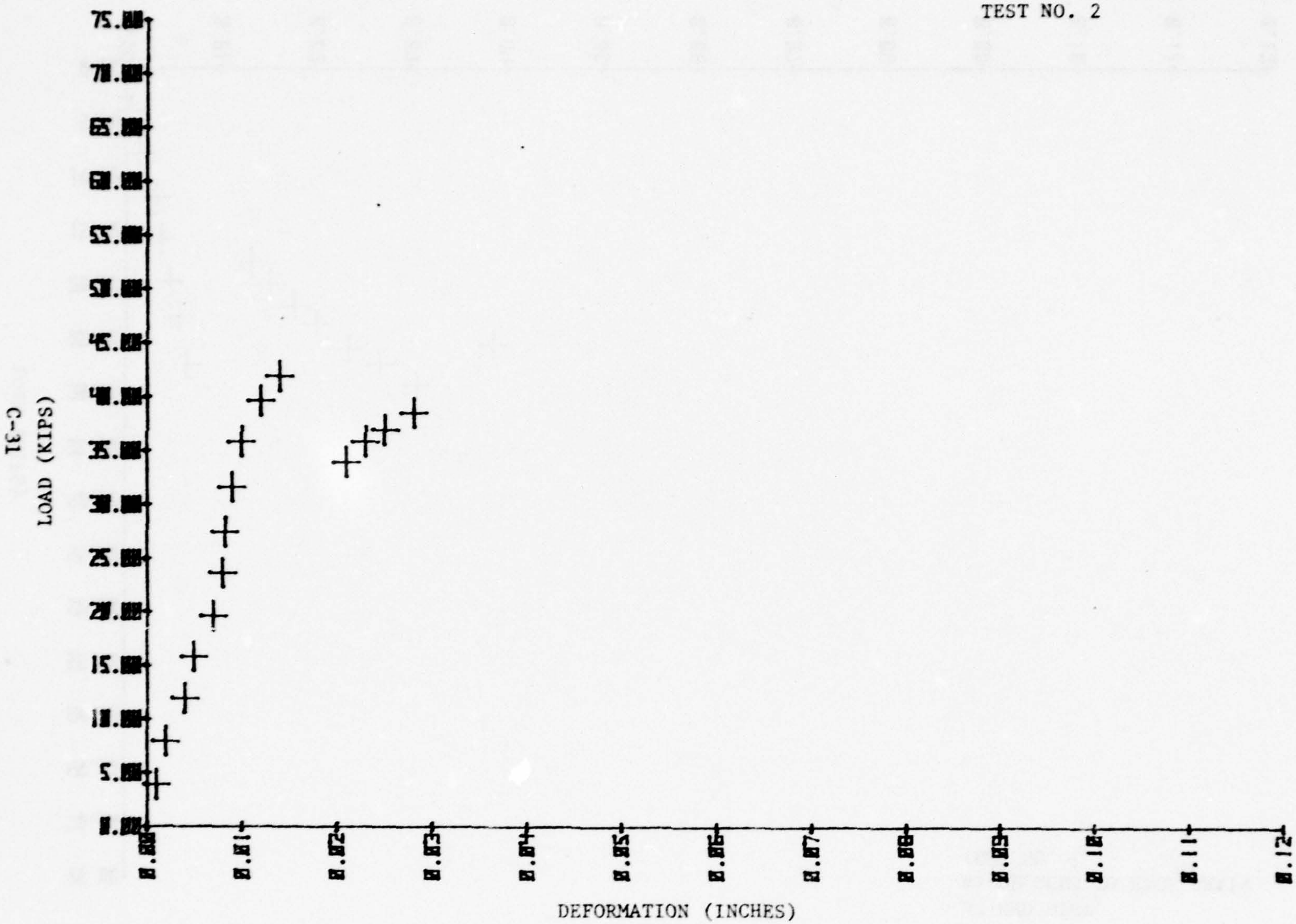
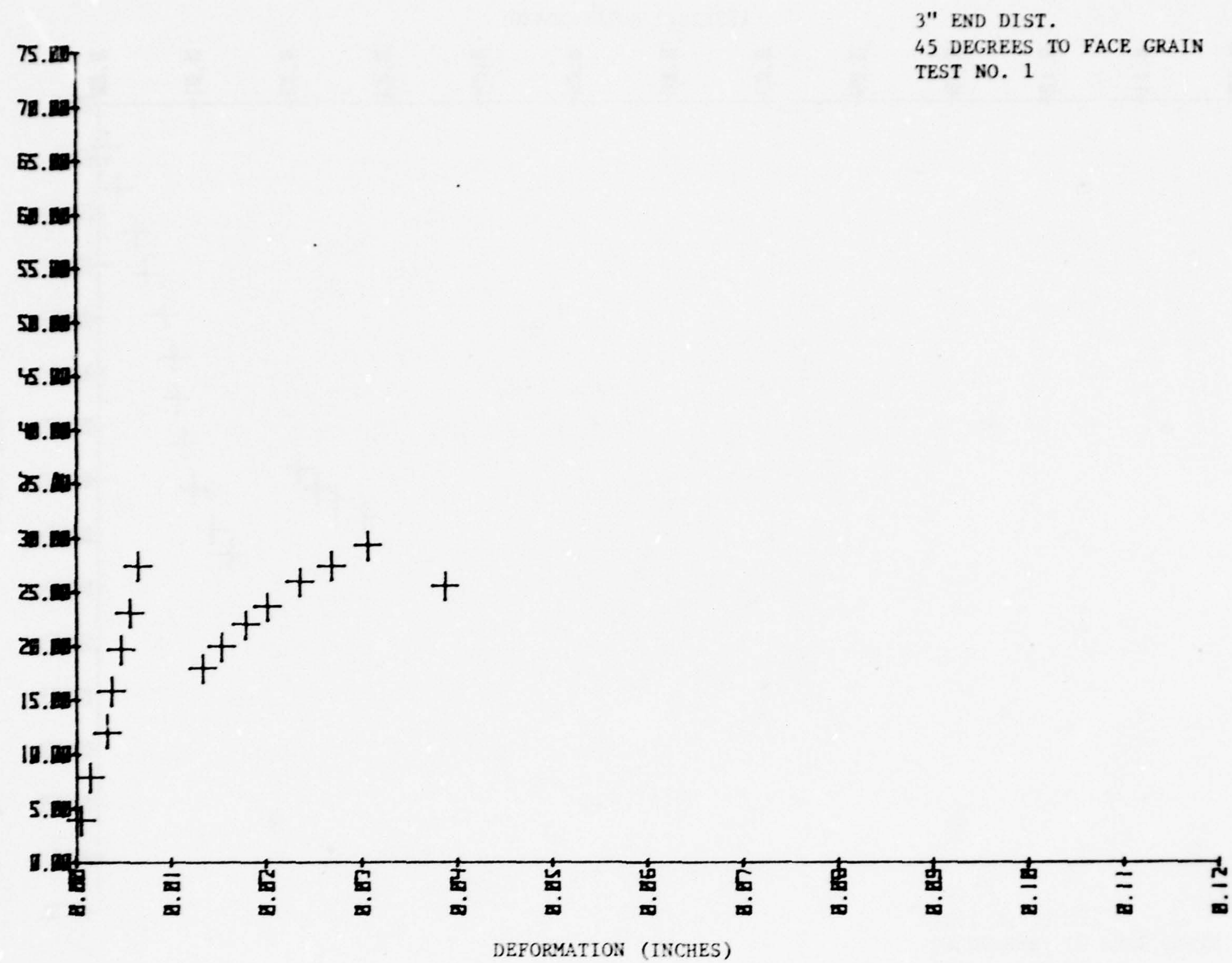
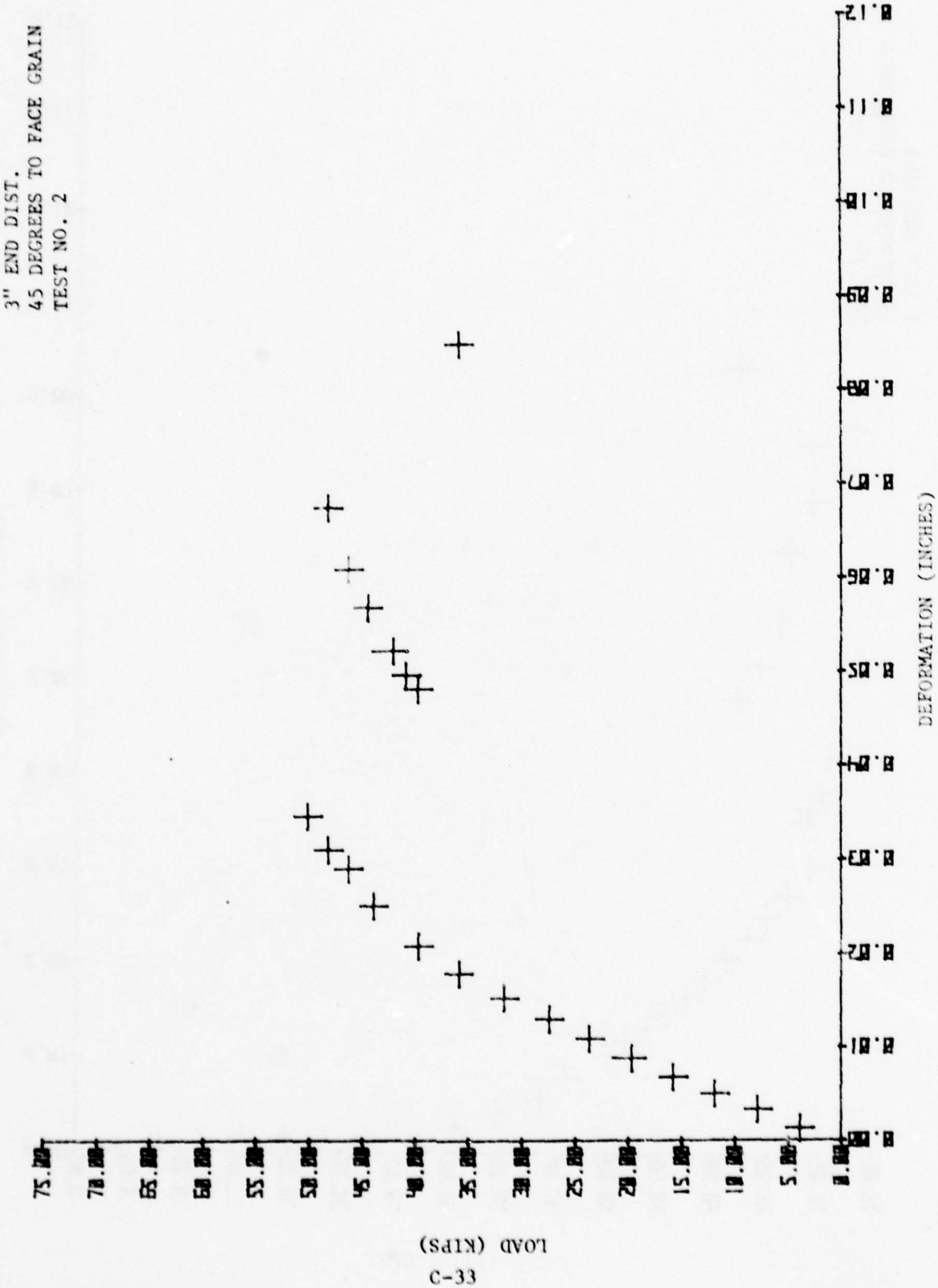
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)


2 1/2" END DIST.
45 DEGREES TO FACE GRAIN
TEST NO. 1
LOAD (KIPS)
DEFORMATION (INCHES)
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12

2 1/2" END DIST.
45 DEGREES TO FACE GRAIN
TEST NO. 2




3" END DIST.
45 DEGREES TO FACE GRAIN
TEST NO. 1
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12


3" END DIST.
45 DEGREES TO FACE GRAIN
TEST NO. 2
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
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55.00
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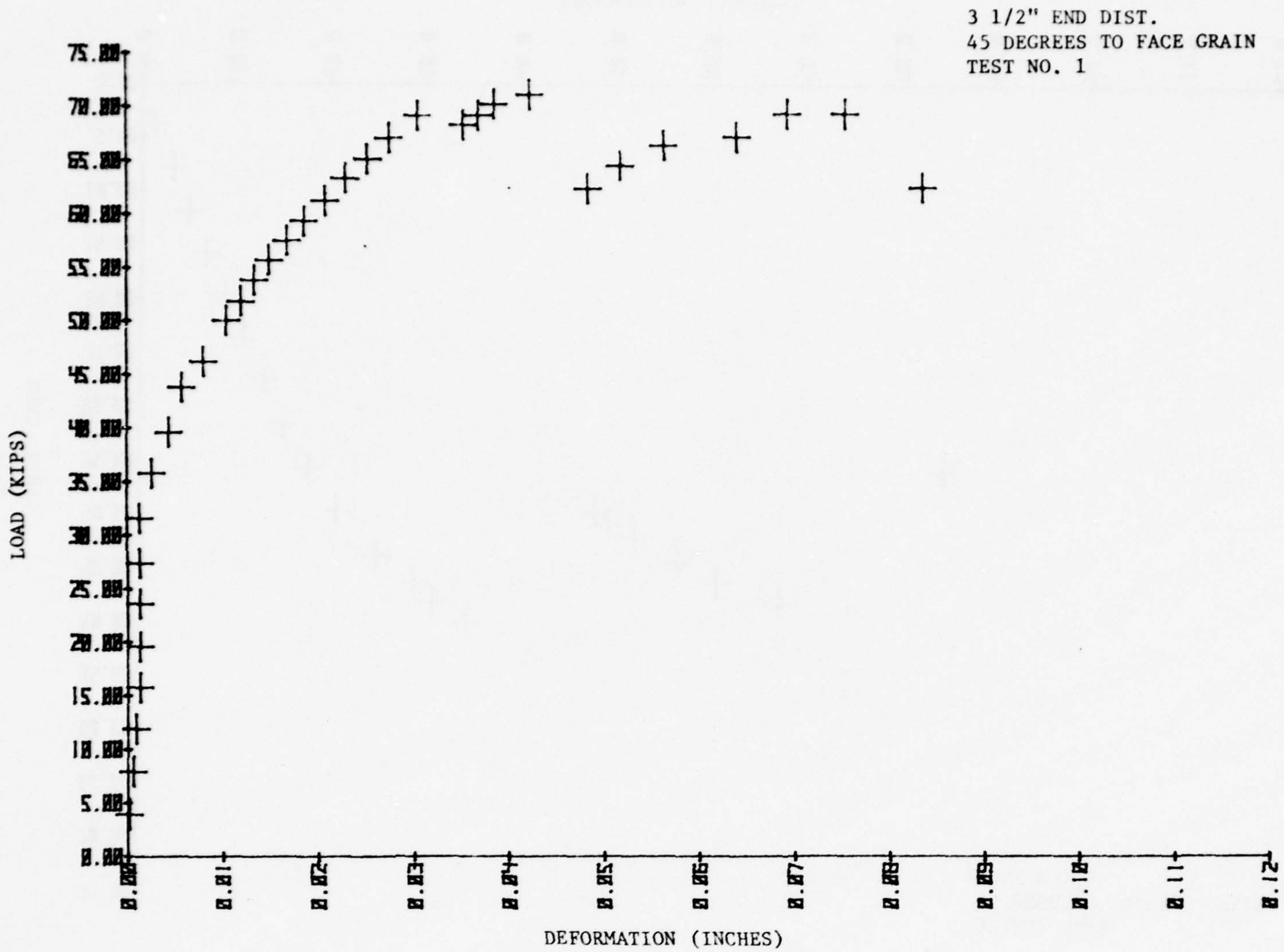
65.00
70.00
75.00


3 1/2" END DIST.
45 DEGREES TO FACE GRAIN
TEST NO. 1
LOAD (KIPS)
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
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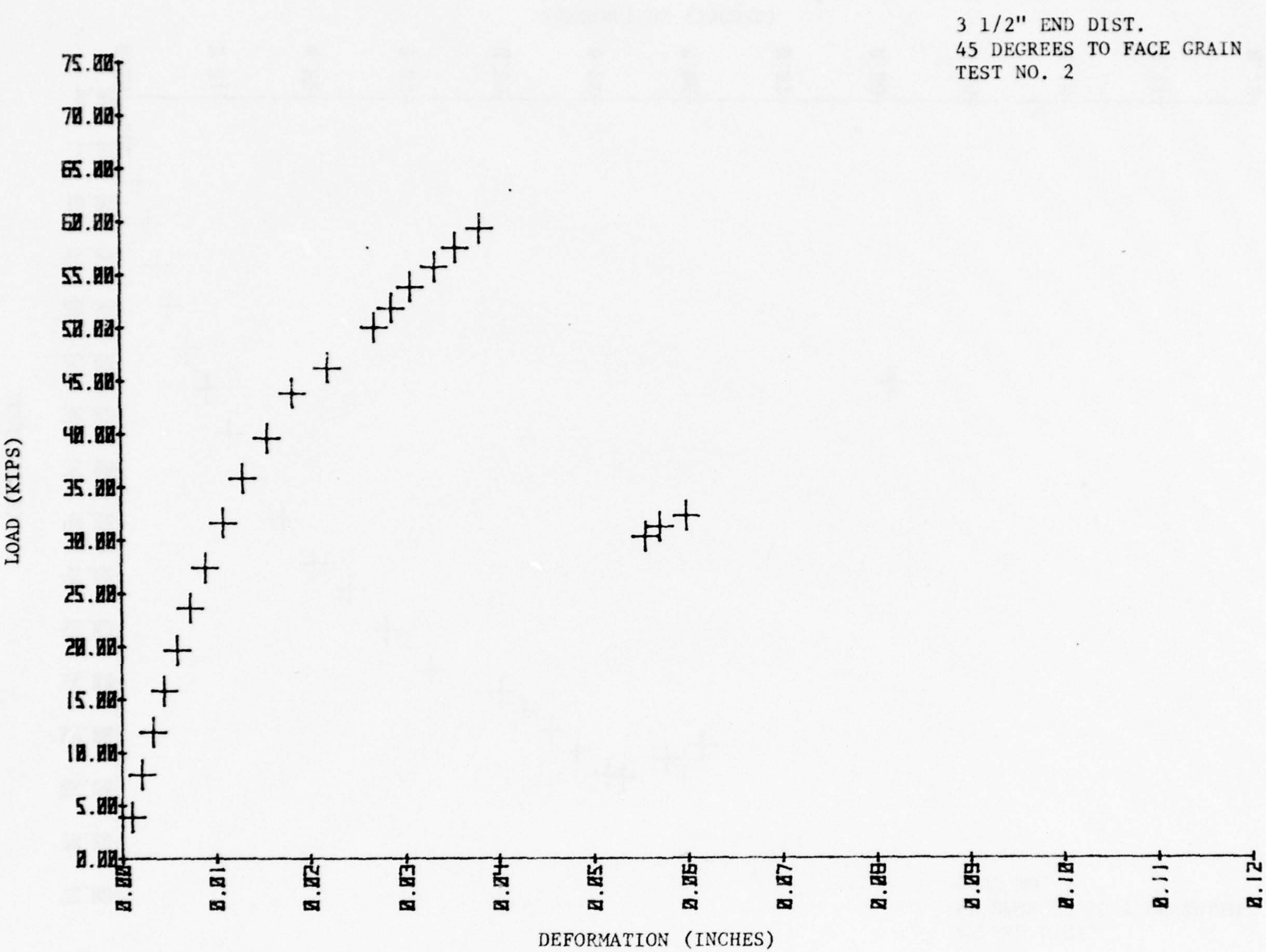
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)



3 1/2" END DIST.
45 DEGREES TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
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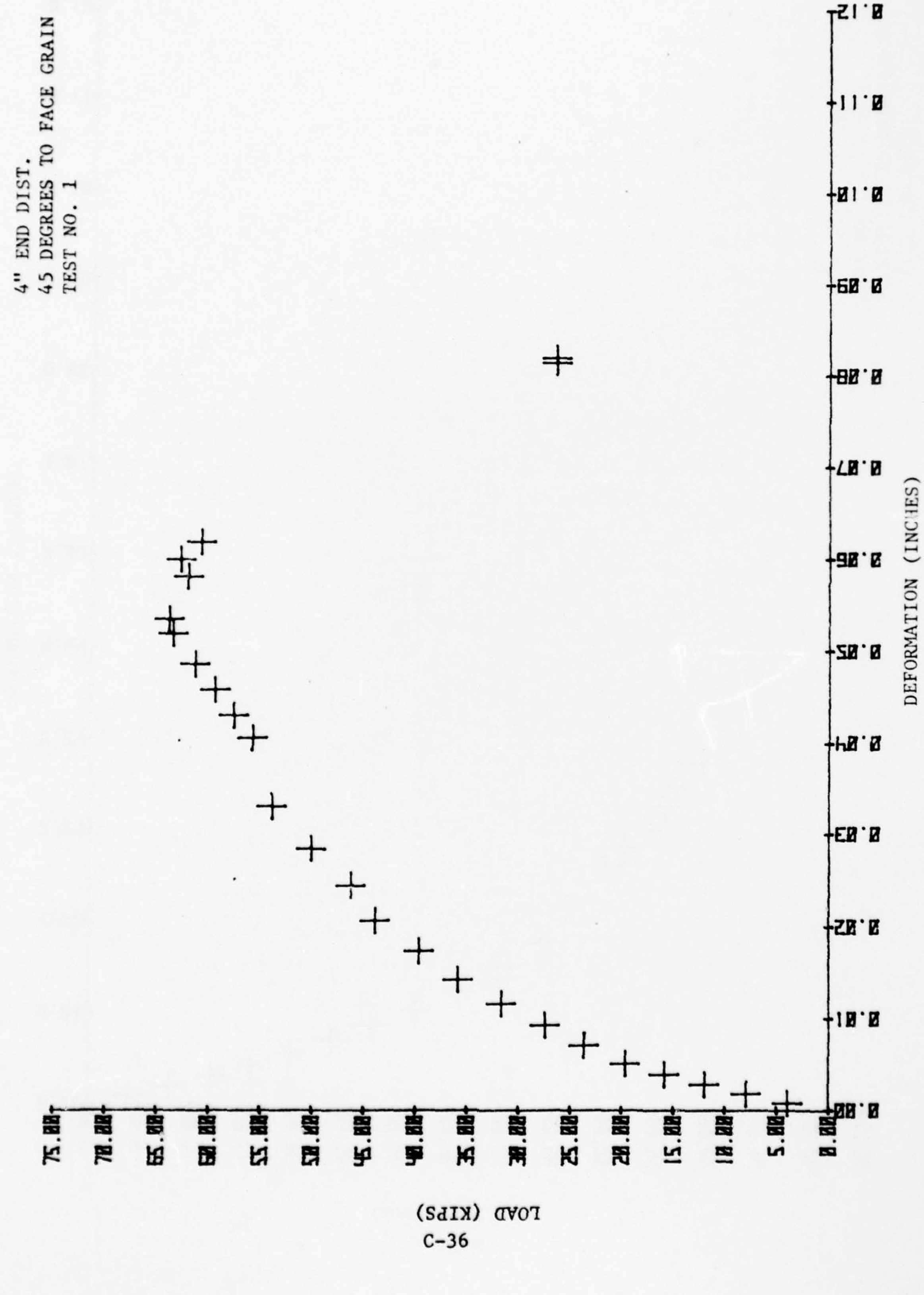
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)


4" END DIST.
45 DEGREES TO FACE GRAIN
TEST NO. 1
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
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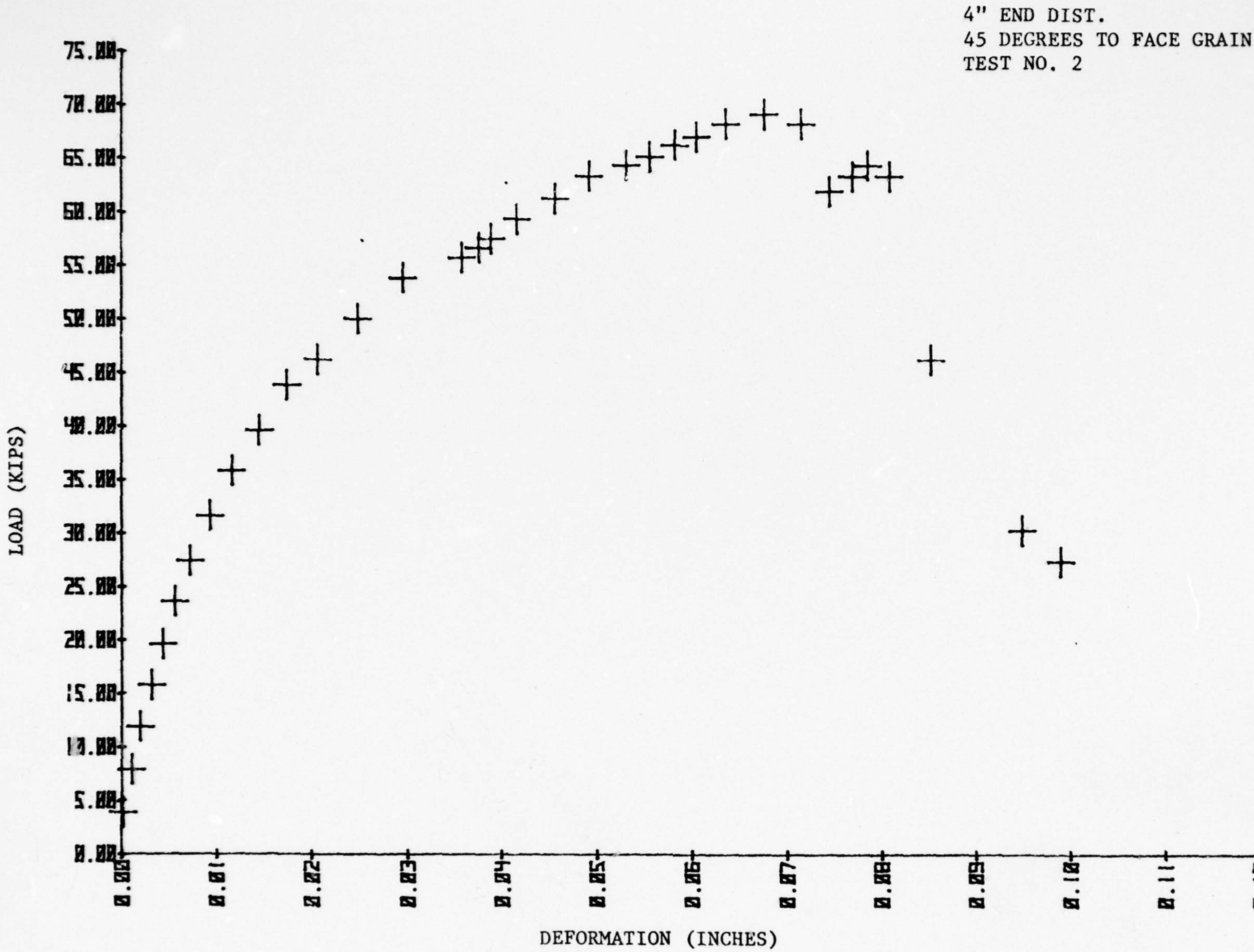
65.00
70.00
75.00


4" END DIST.
45 DEGREES TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
DEFORMATION (INCHES)
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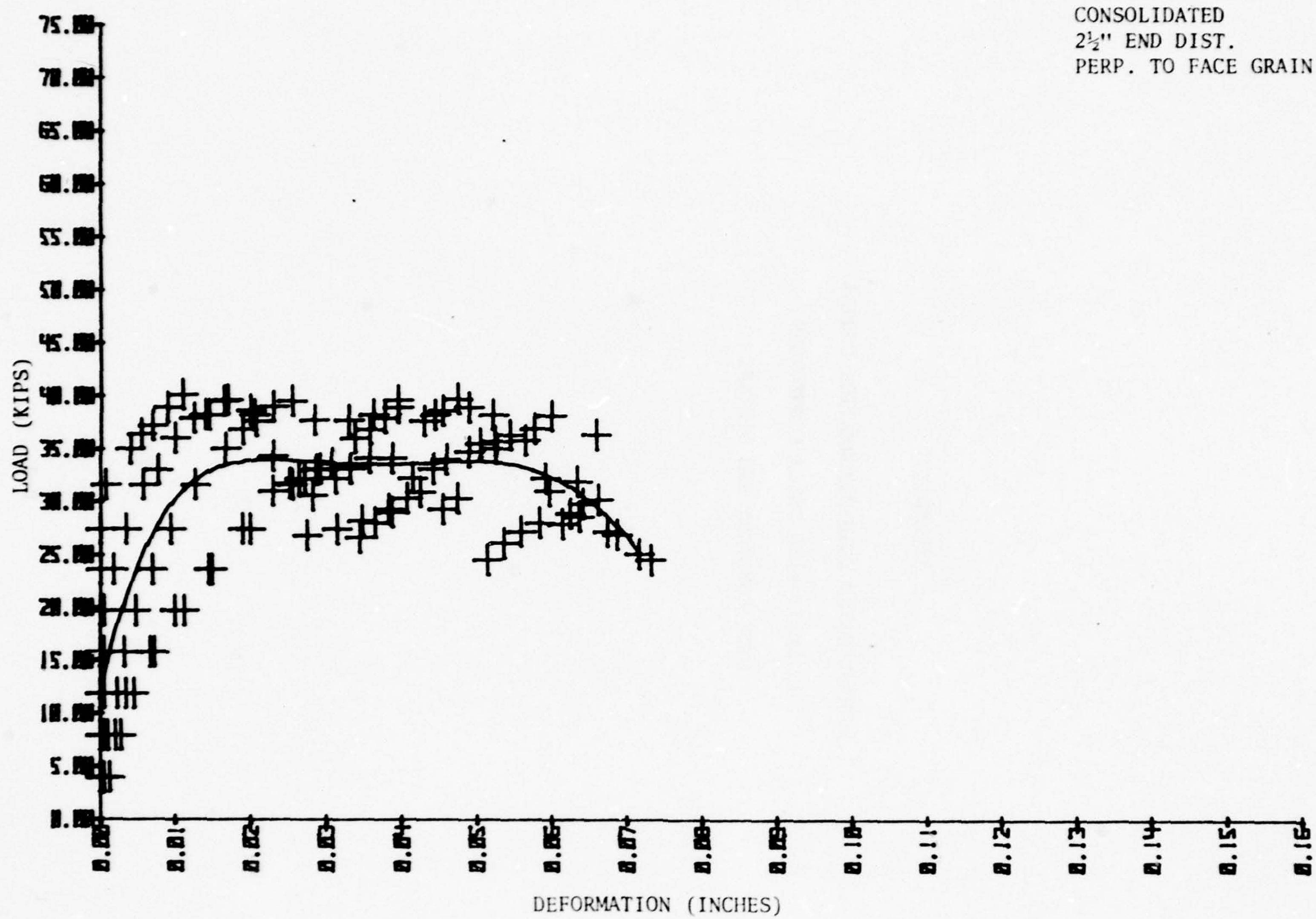
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12

APPENDIX D

CONSOLIDATED LOAD-DEFORMATION CURVES
FOR SPLIT-RING SHEAR CONNECTORS
WITH CONSTANT END DISTANCE


CONSOLIDATED
2½" END DIST.
PERP. TO FACE GRAIN
LOAD (KIPS)
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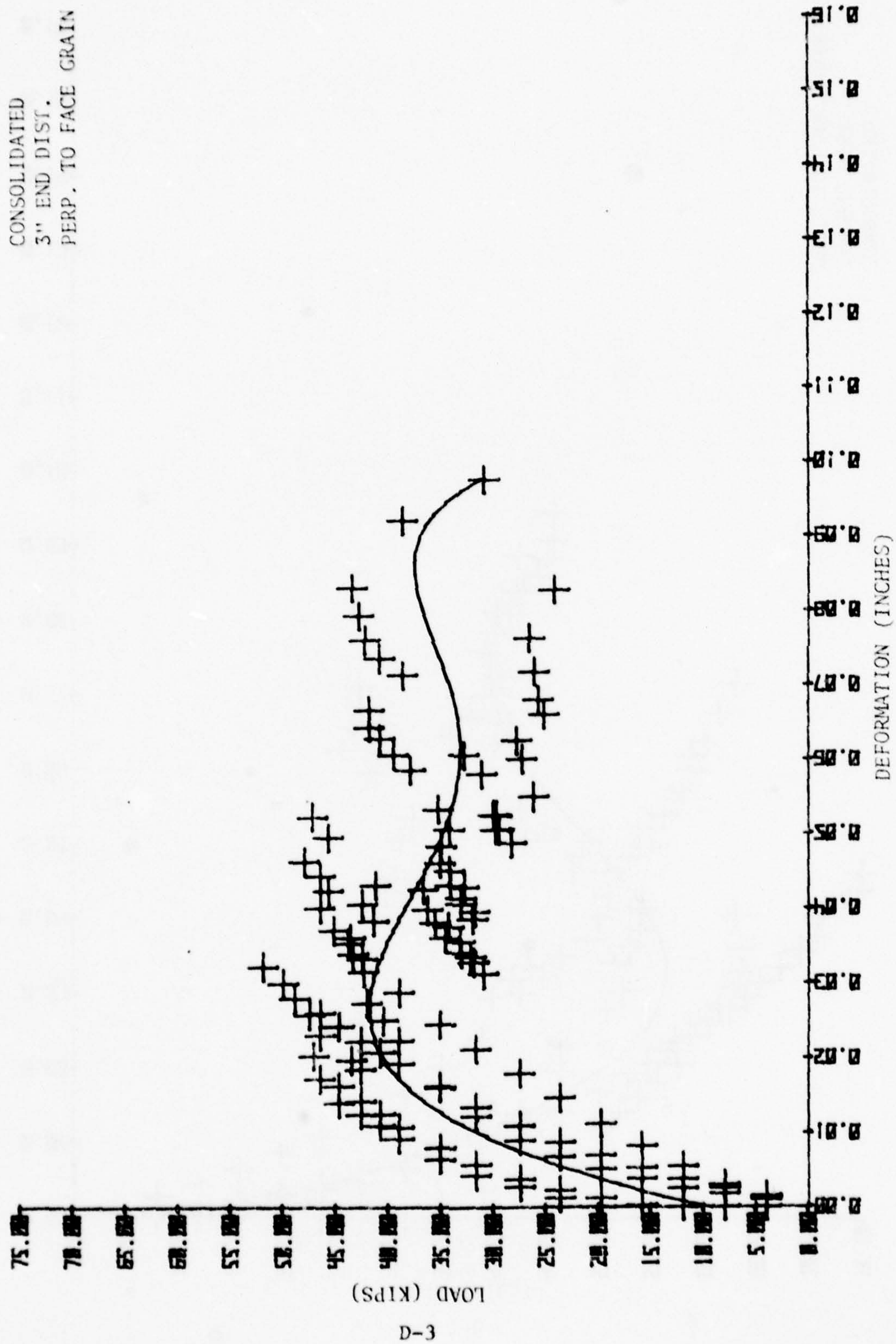
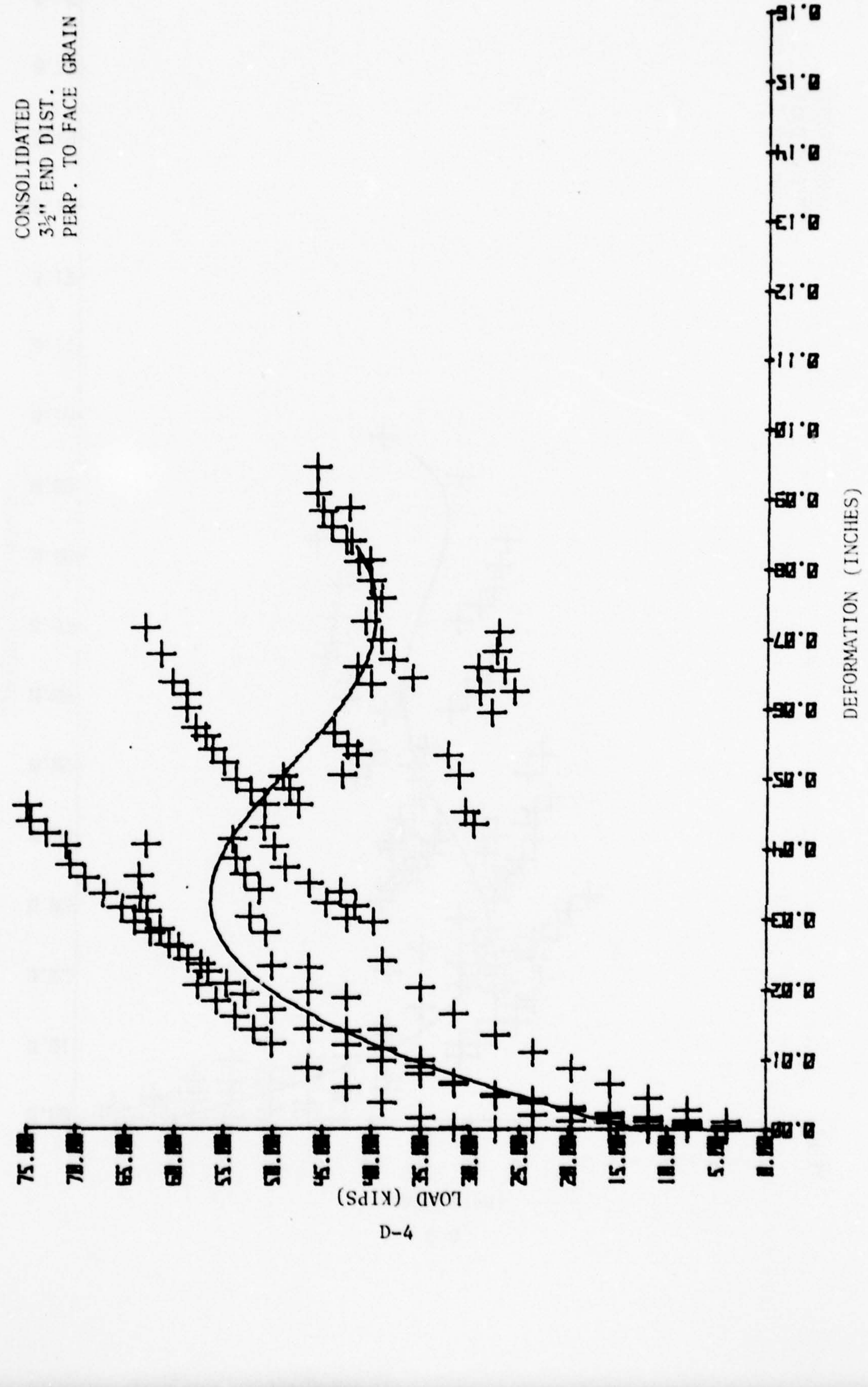
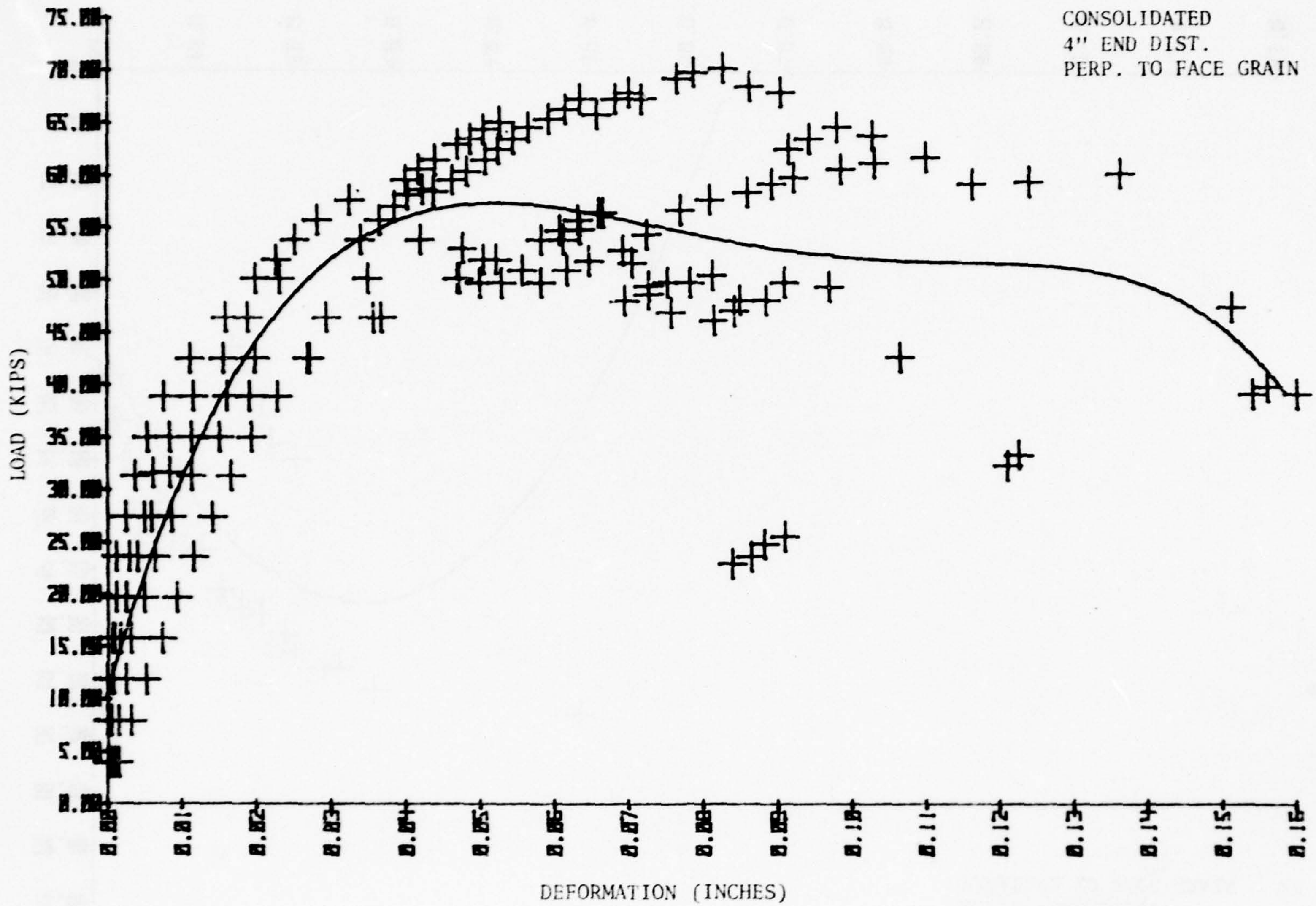
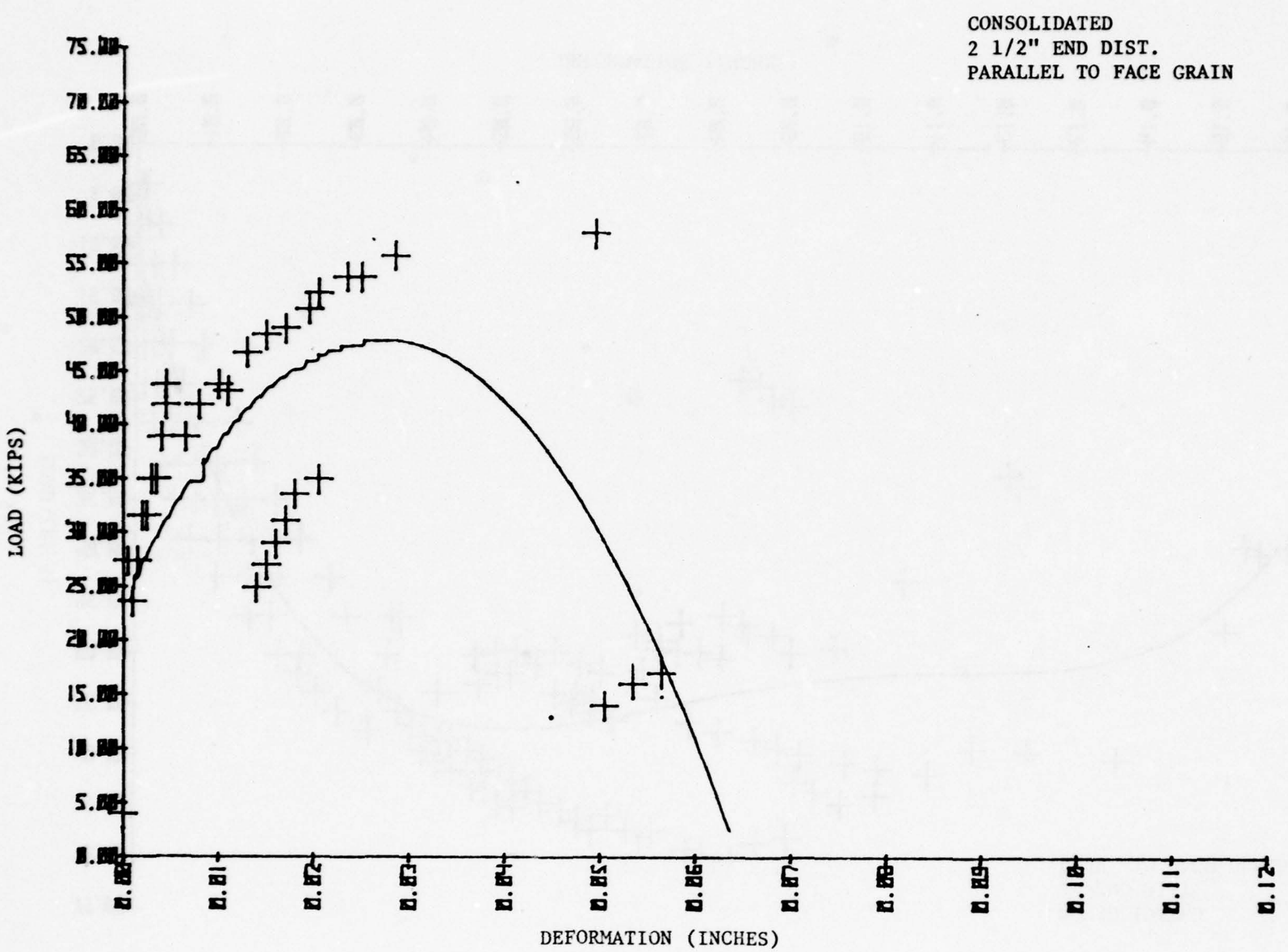
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
DEFORMATION (INCHES)


CONSOLIDATED
3" END DIST.
PERP. TO FACE GRAIN
LOAD (KIPS)
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00



CONSOLIDATED
3½" END DIST.
PERP. TO FACE GRAIN
LOAD (KIPS)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16


CONSOLIDATED
4" END DIST.
PERP. TO FACE GRAIN
LOAD (KIPS)
DEFORMATION (INCHES)
75.000
70.000
65.000
60.000
55.000
50.000
45.000
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16


CONSOLIDATED
2 1/2" END DIST.
PARALLEL TO FACE GRAIN
LOAD (KIPS)
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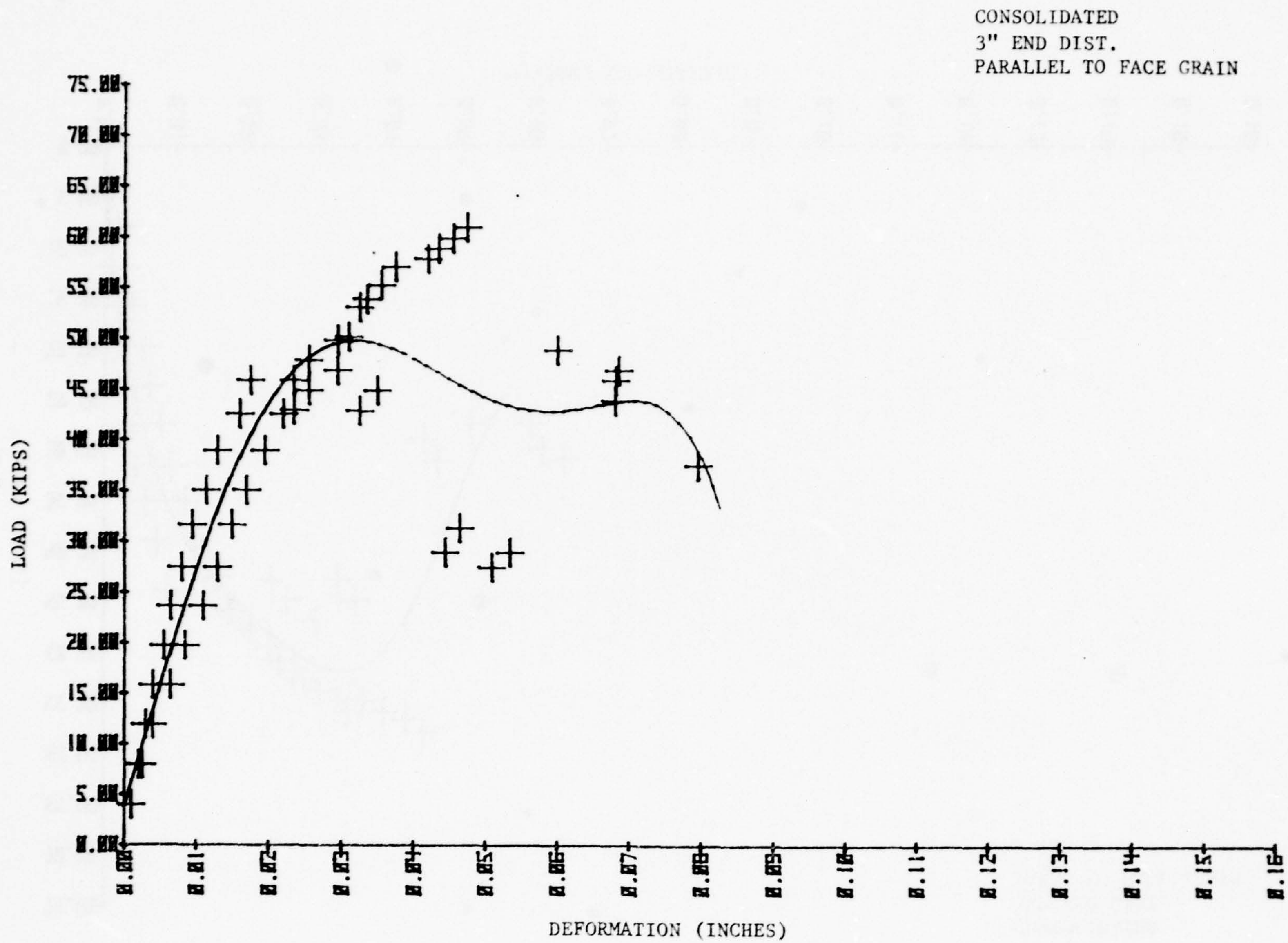
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)


CONSOLIDATED
3" END DIST.
PARALLEL TO FACE GRAIN
LOAD (KIPS)
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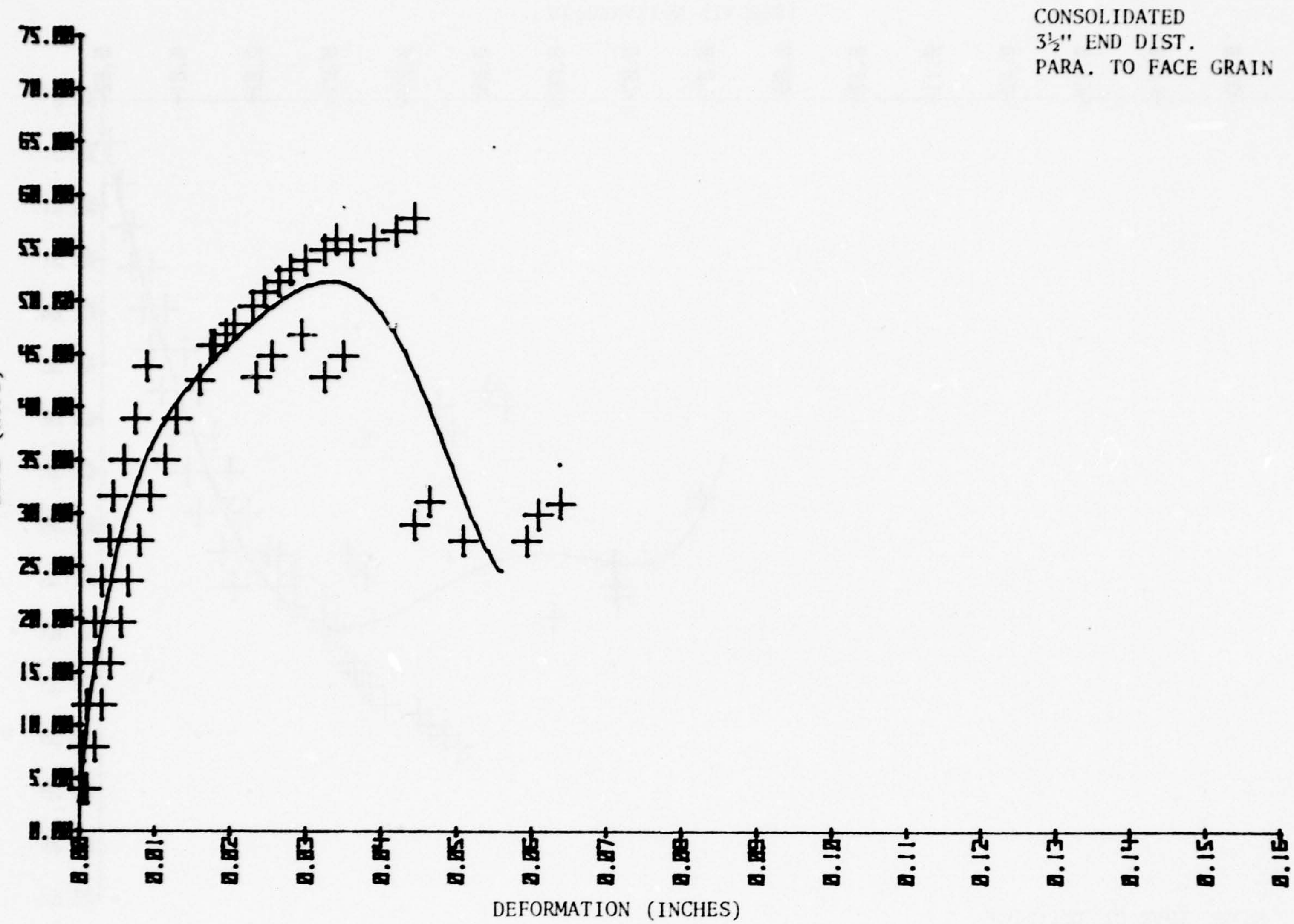
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
DEFORMATION (INCHES)


CONSOLIDATED
3½" END DIST.
PARA. TO FACE GRAIN
LOAD (KIPS)
DEFORMATION (INCHES)
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
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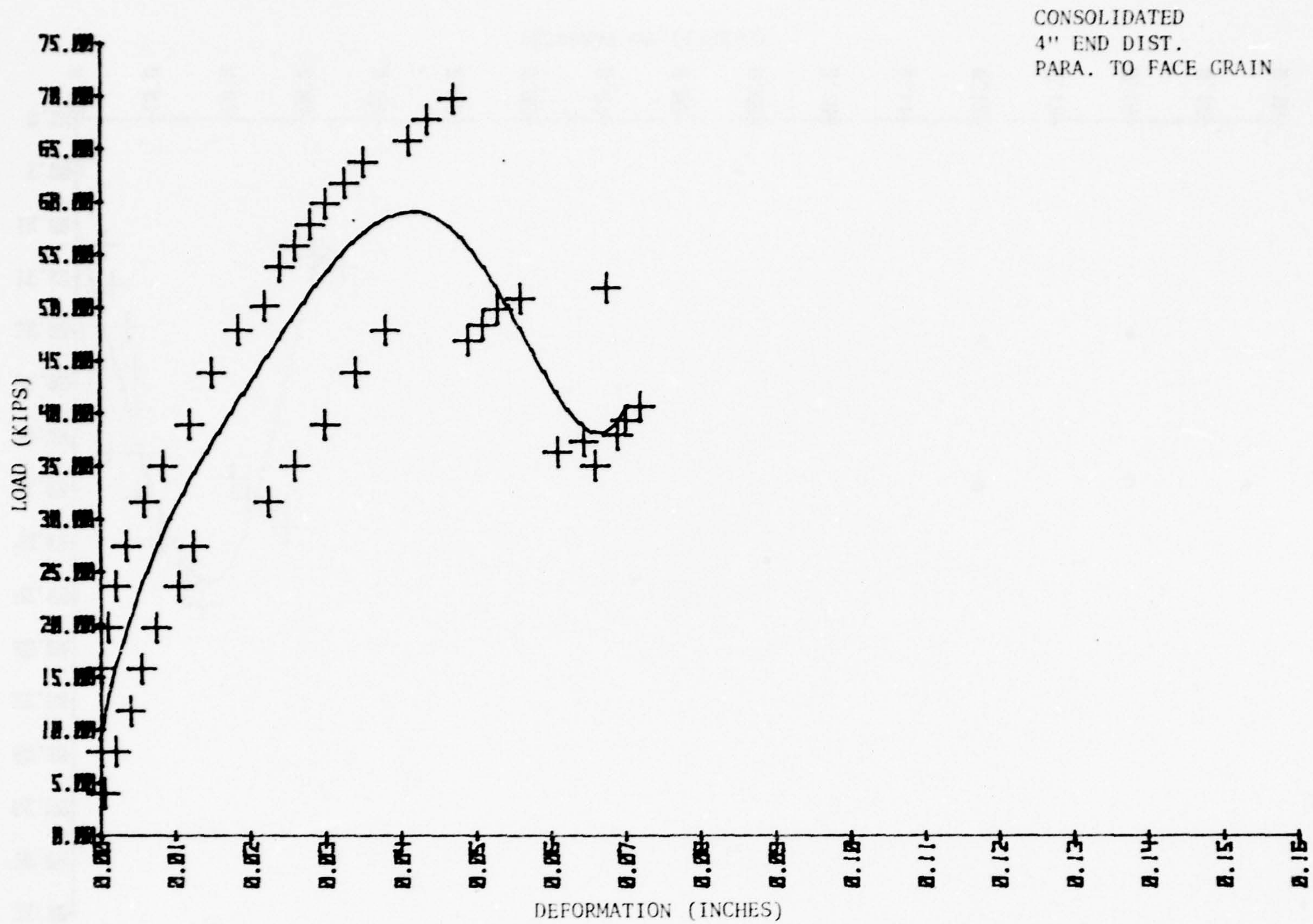
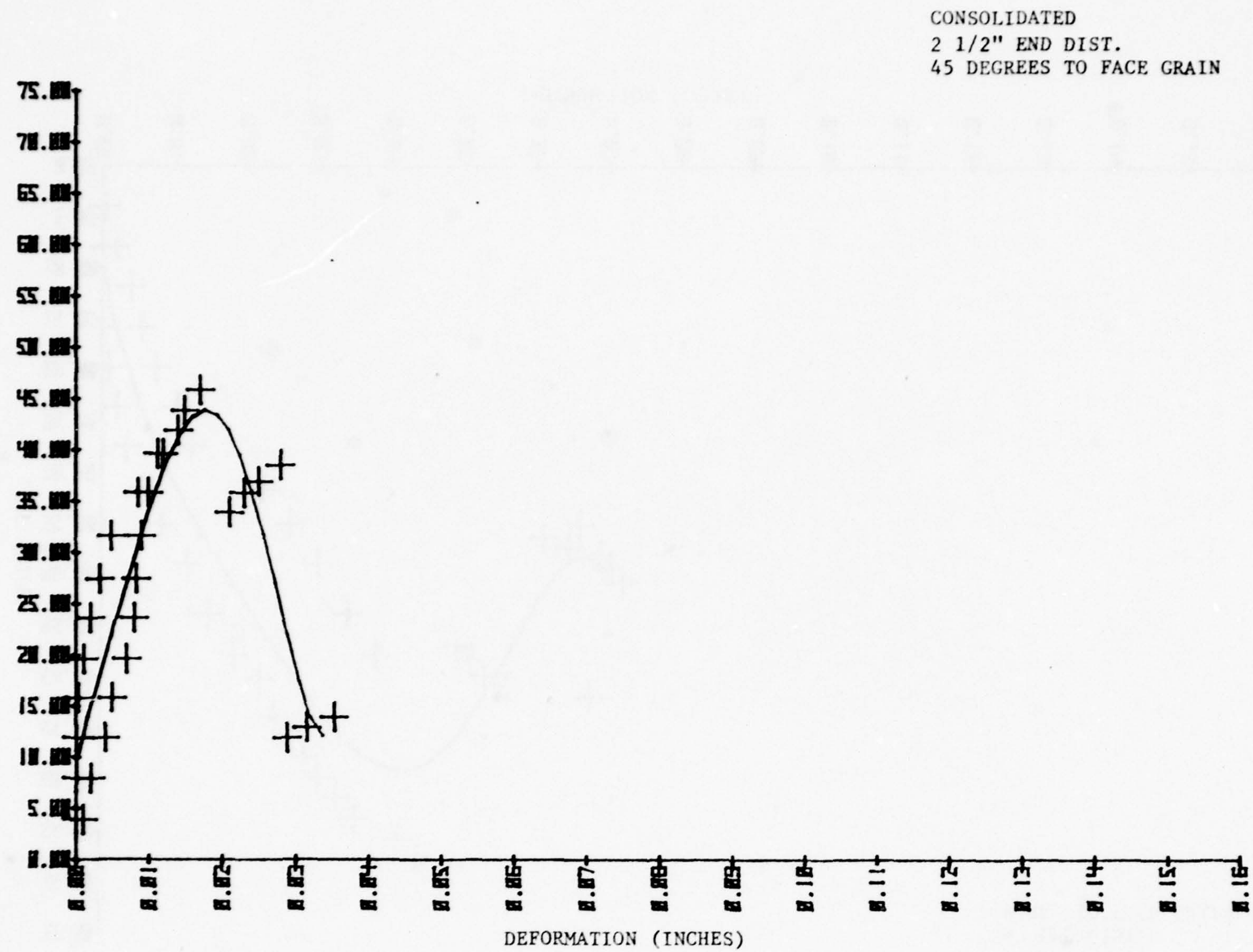
0.10
0.11
0.12
0.13
0.14
0.15
0.16


CONSOLIDATED
4" END DIST.
PARA. TO FACE GRAIN
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16


CONSOLIDATED
2 1/2" END DIST.
45 DEGREES TO FACE GRAIN
LOAD (KIPS)
DEFORMATION (INCHES)
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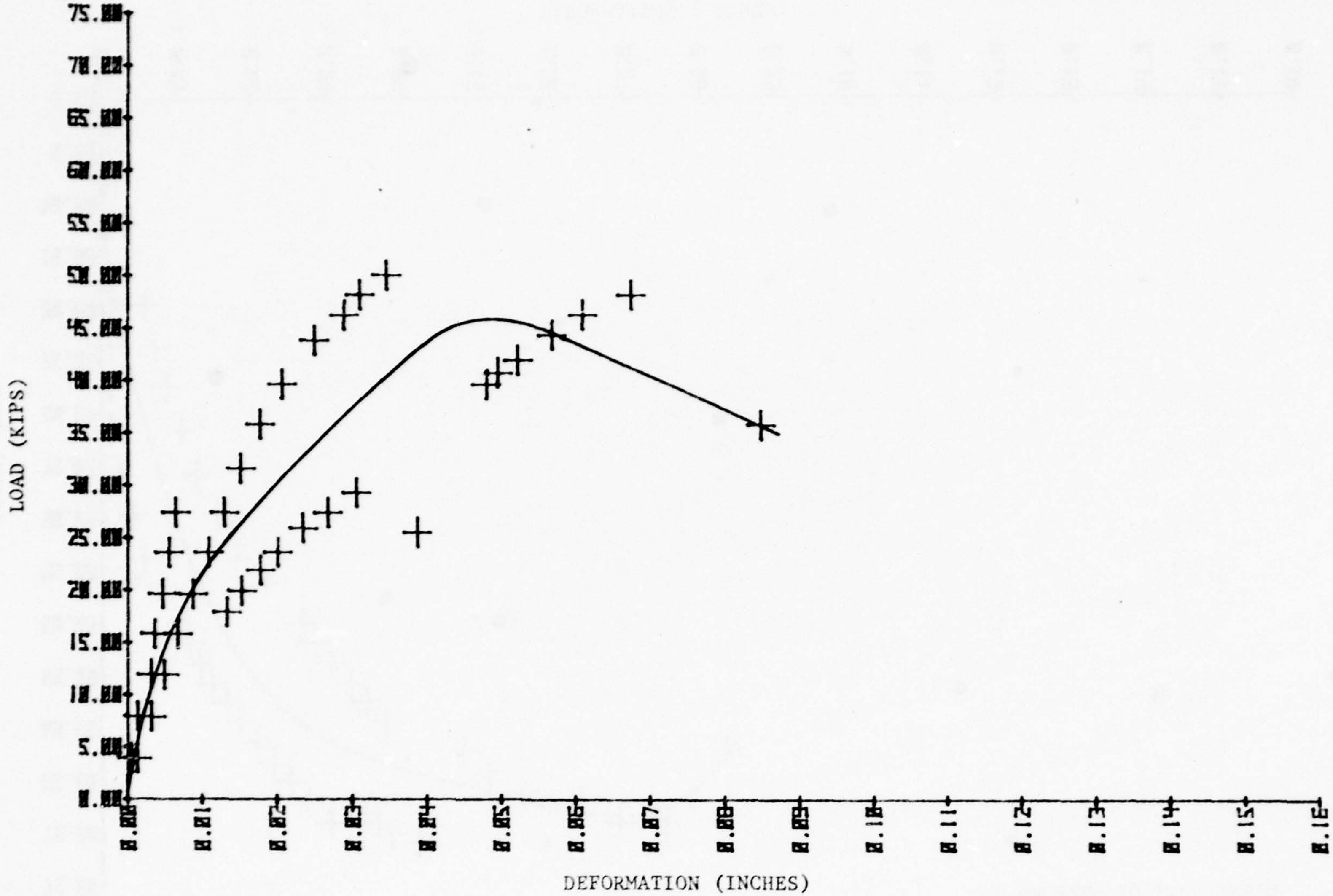
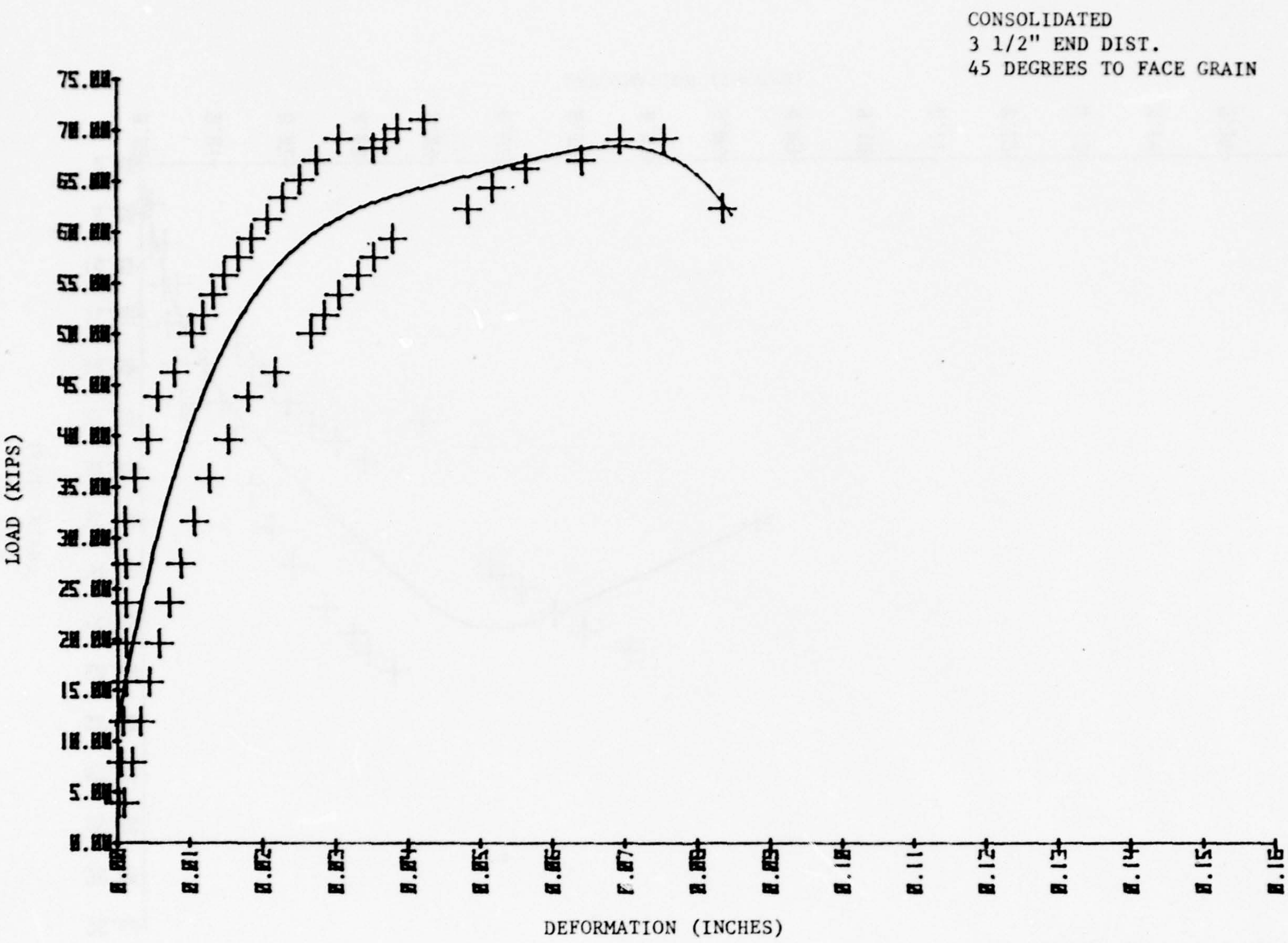
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16

CONSOLIDATED
3" END DIST.
45 DEGREES TO FACE GRAIN




CONSOLIDATED
3 1/2" END DIST.
45 DEGREES TO FACE GRAIN
LOAD (KIPS)
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60.00
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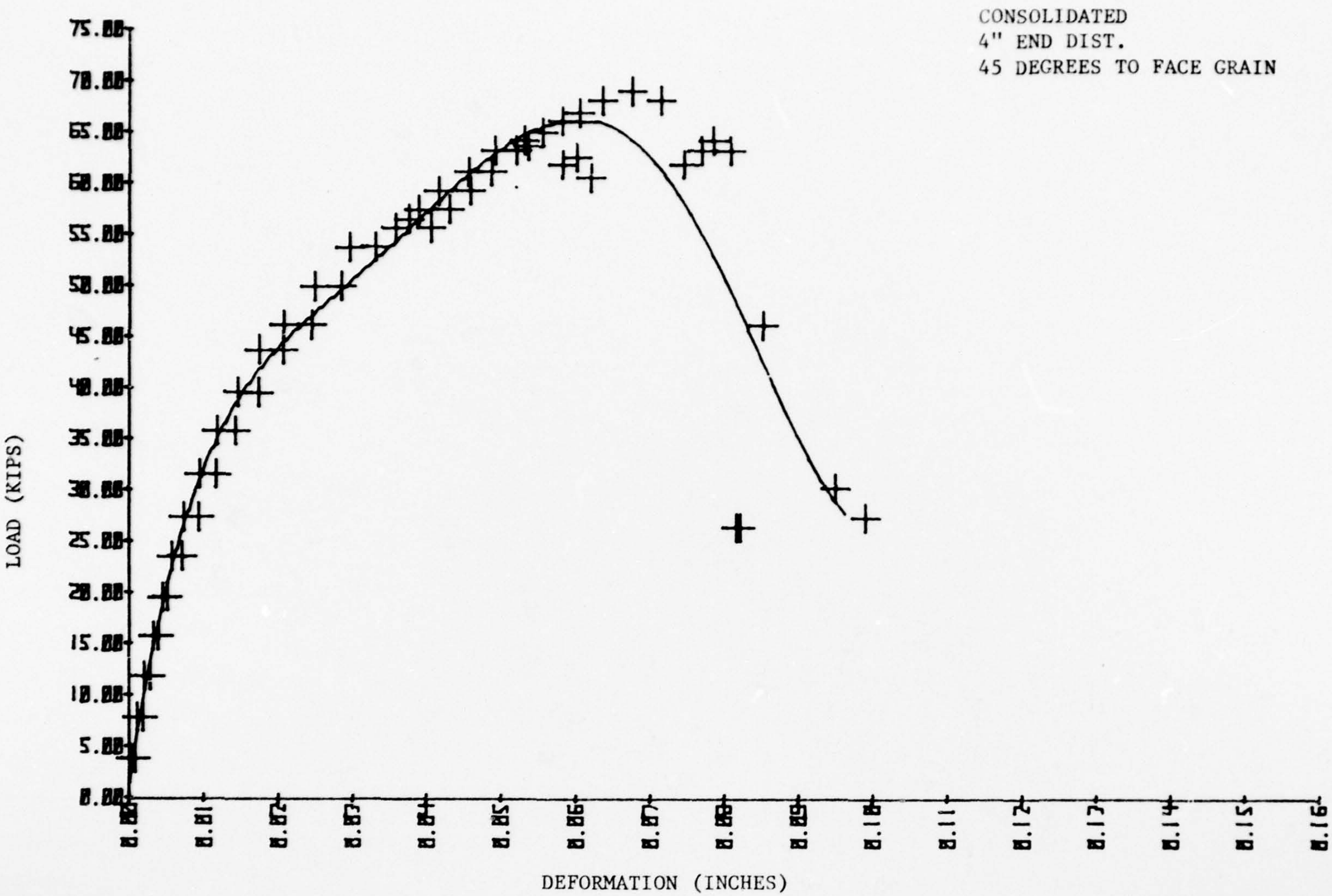
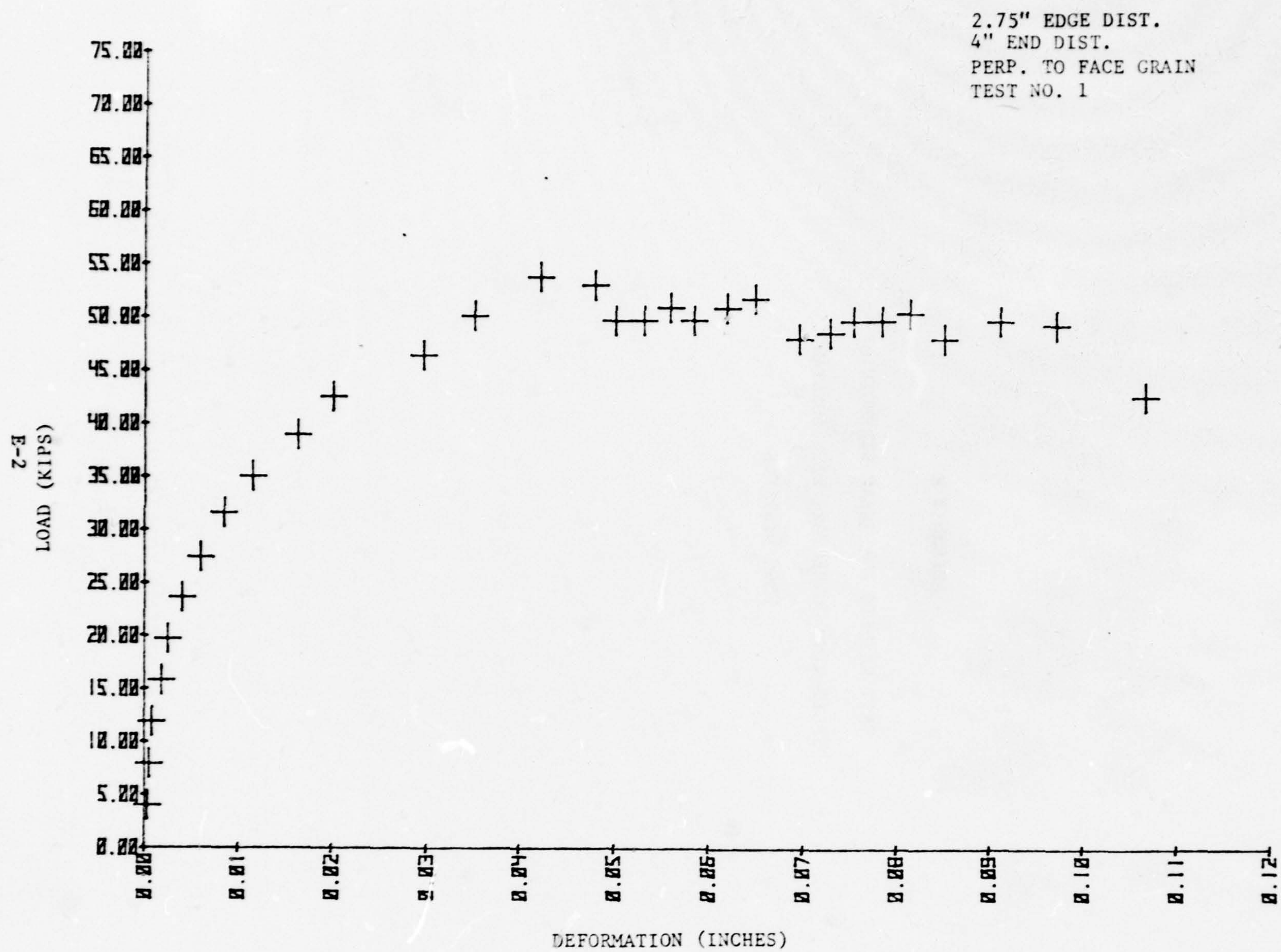
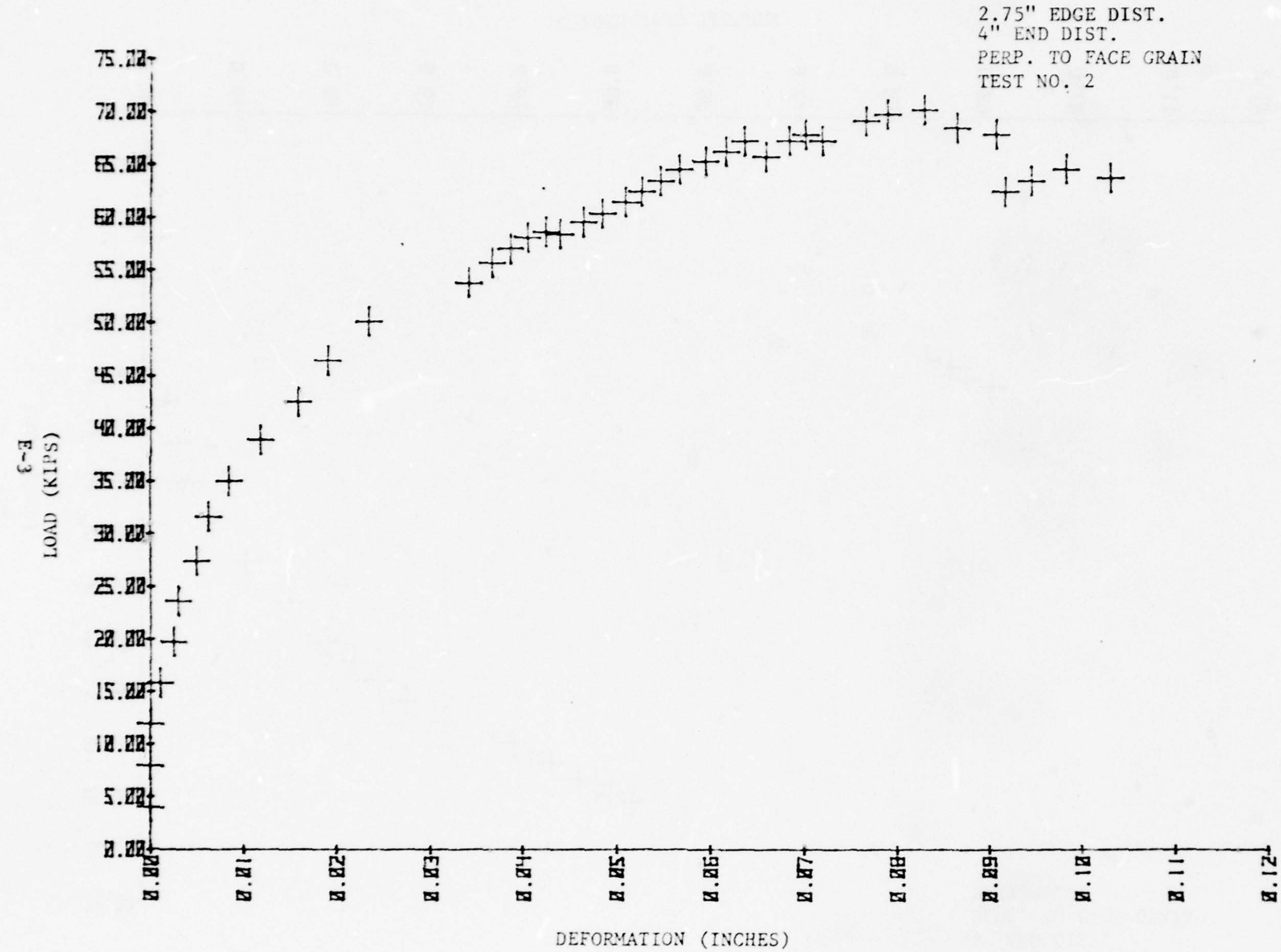
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
DEFORMATION (INCHES)

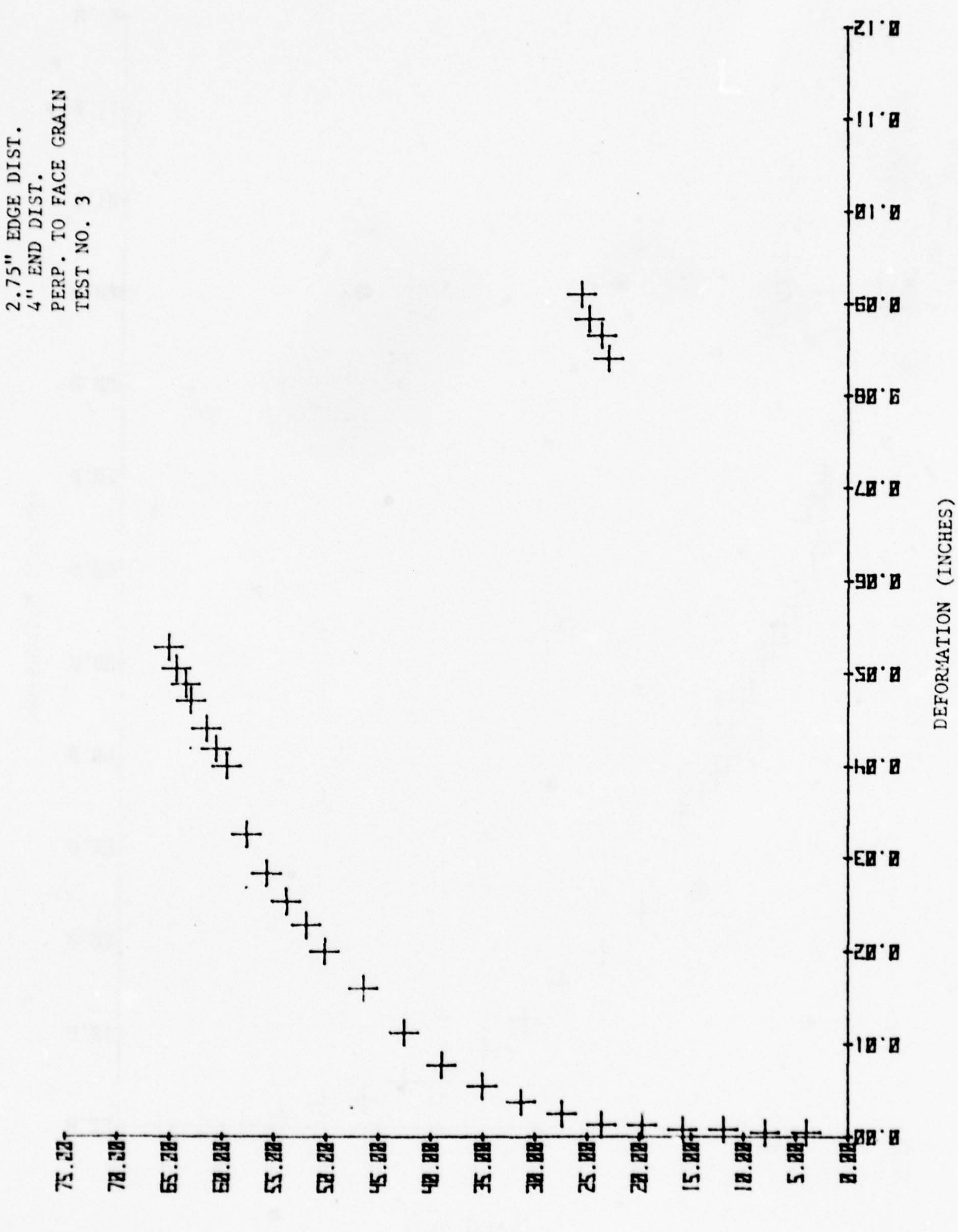

CONSOLIDATED
4" END DIST.
45 DEGREES TO FACE GRAIN
LOAD (KIPS)
DEFORMATION (INCHES)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16

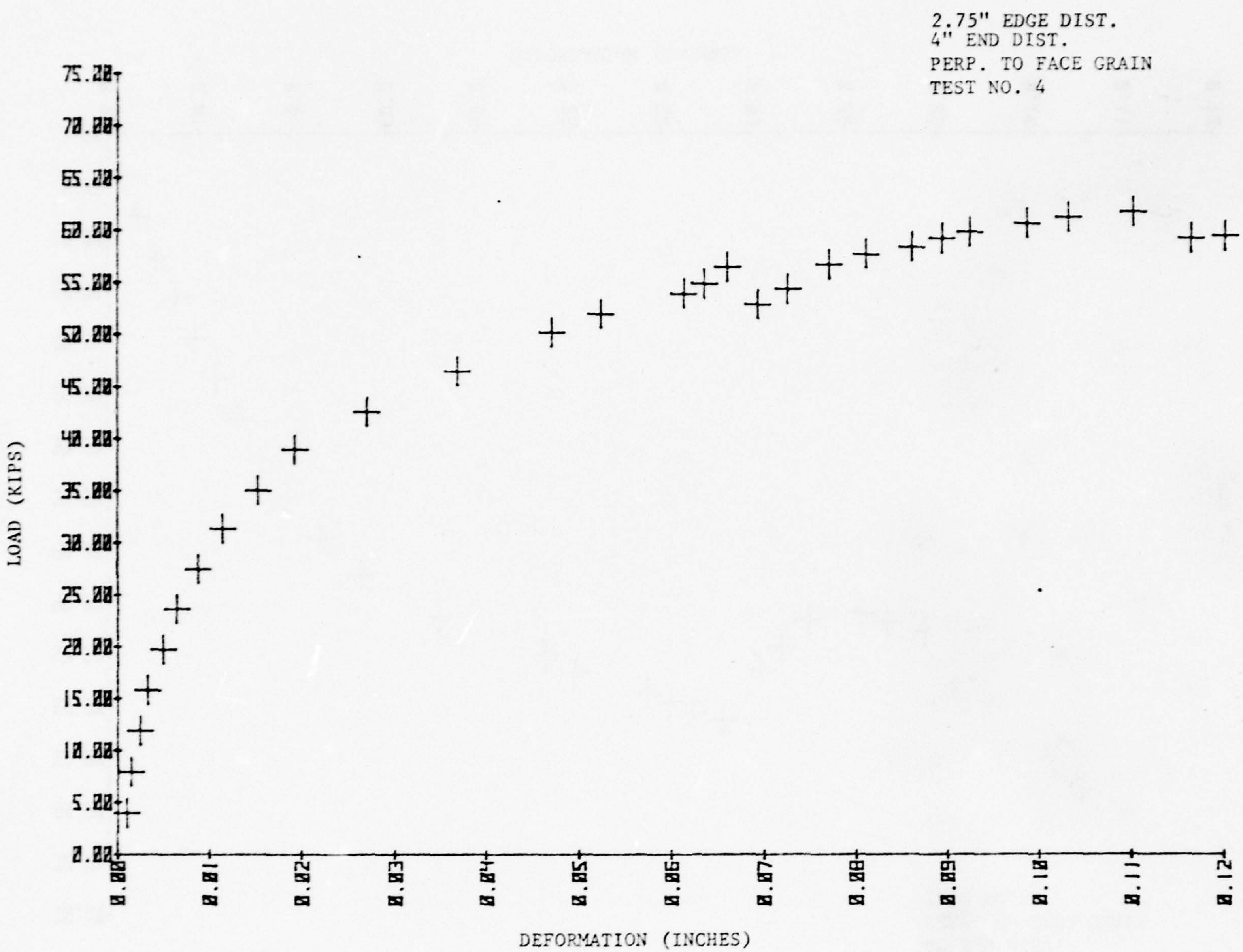
APPENDIX E

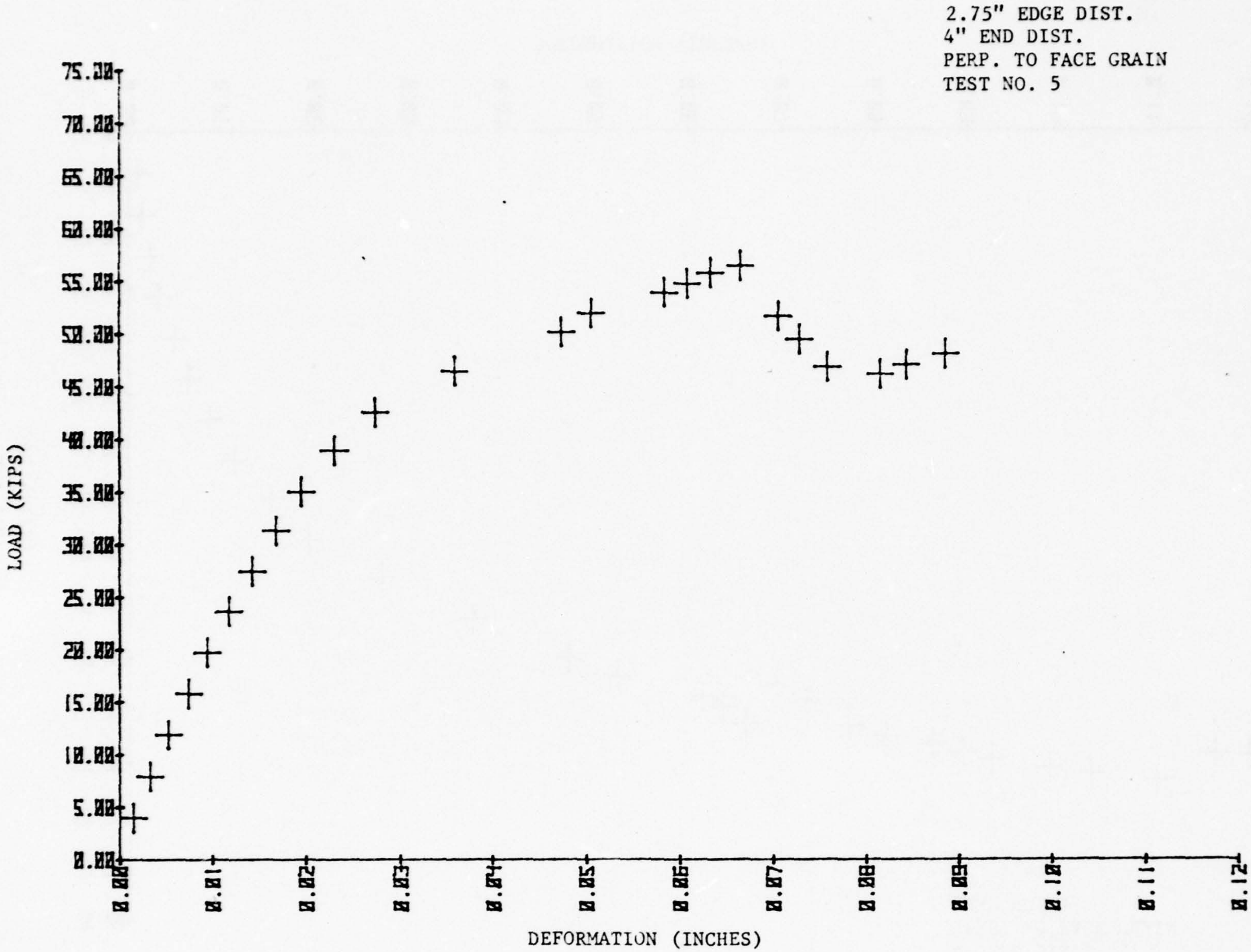
TEST RESULTS FOR SHEAR STRENGTH OF SPLIT-RING CONNECTORS WITH CONSTANT EDGE DISTANCE

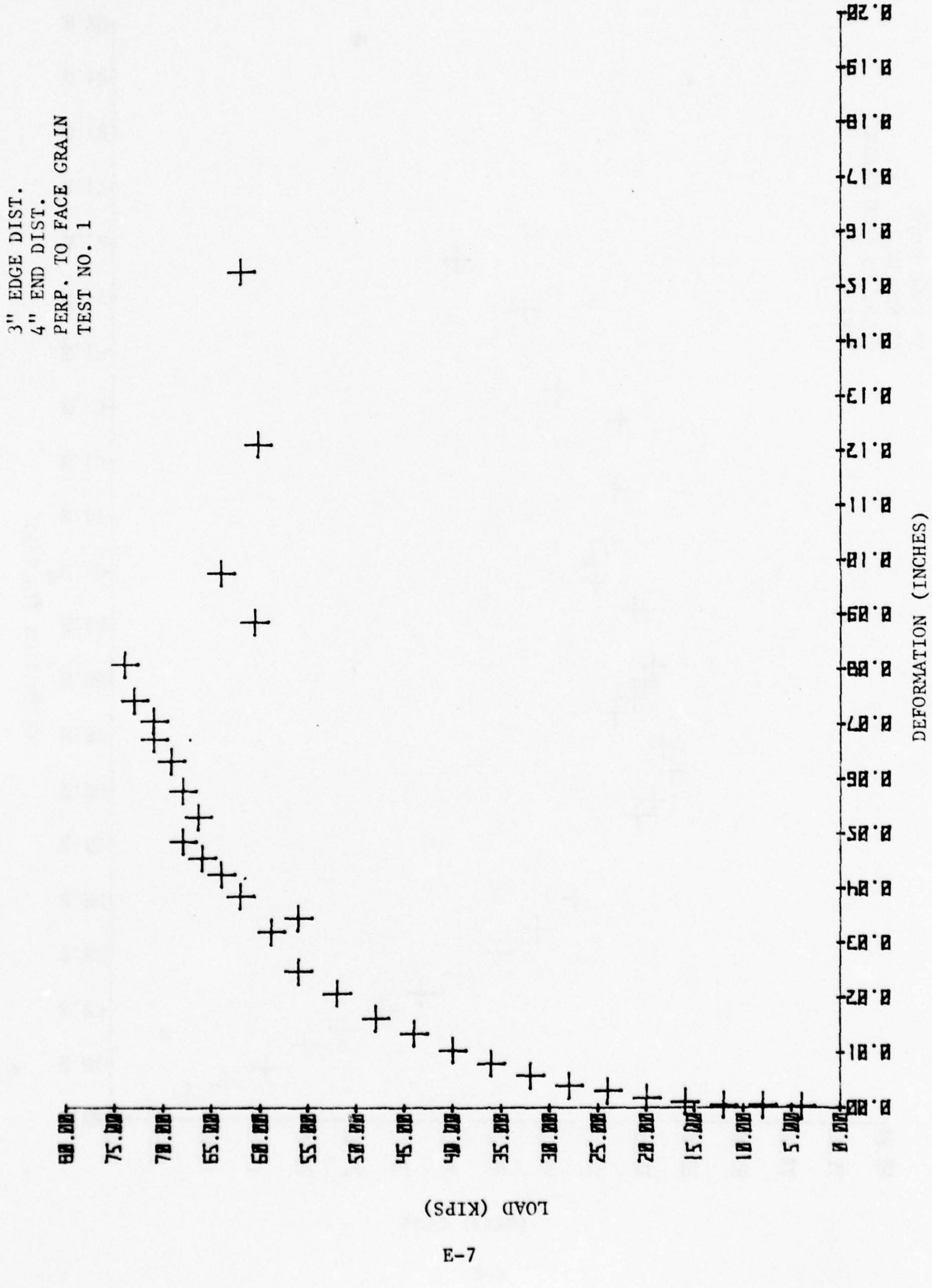

2.75" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 1
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)

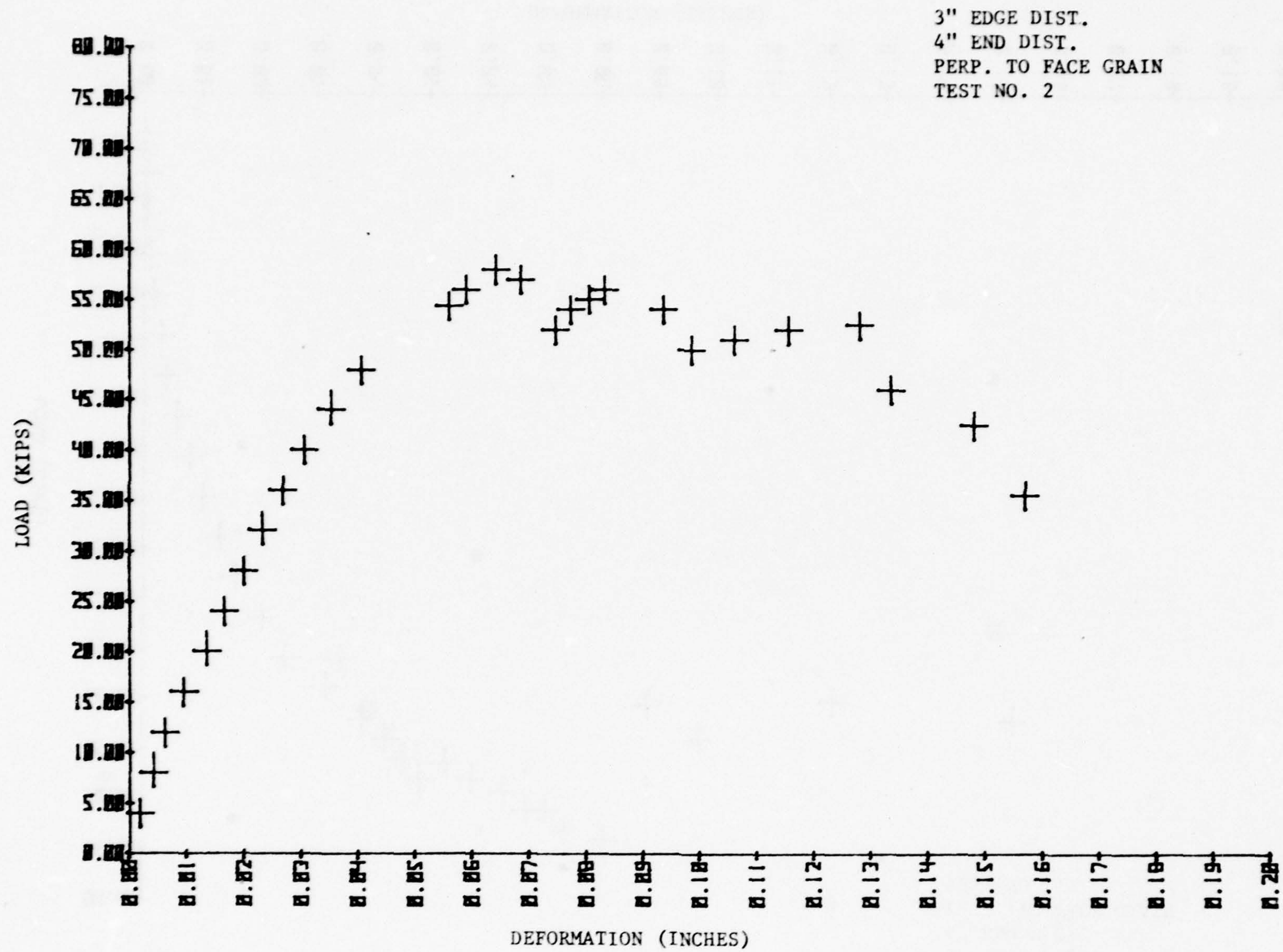

2.75" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
DEFORMATION (INCHES)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12

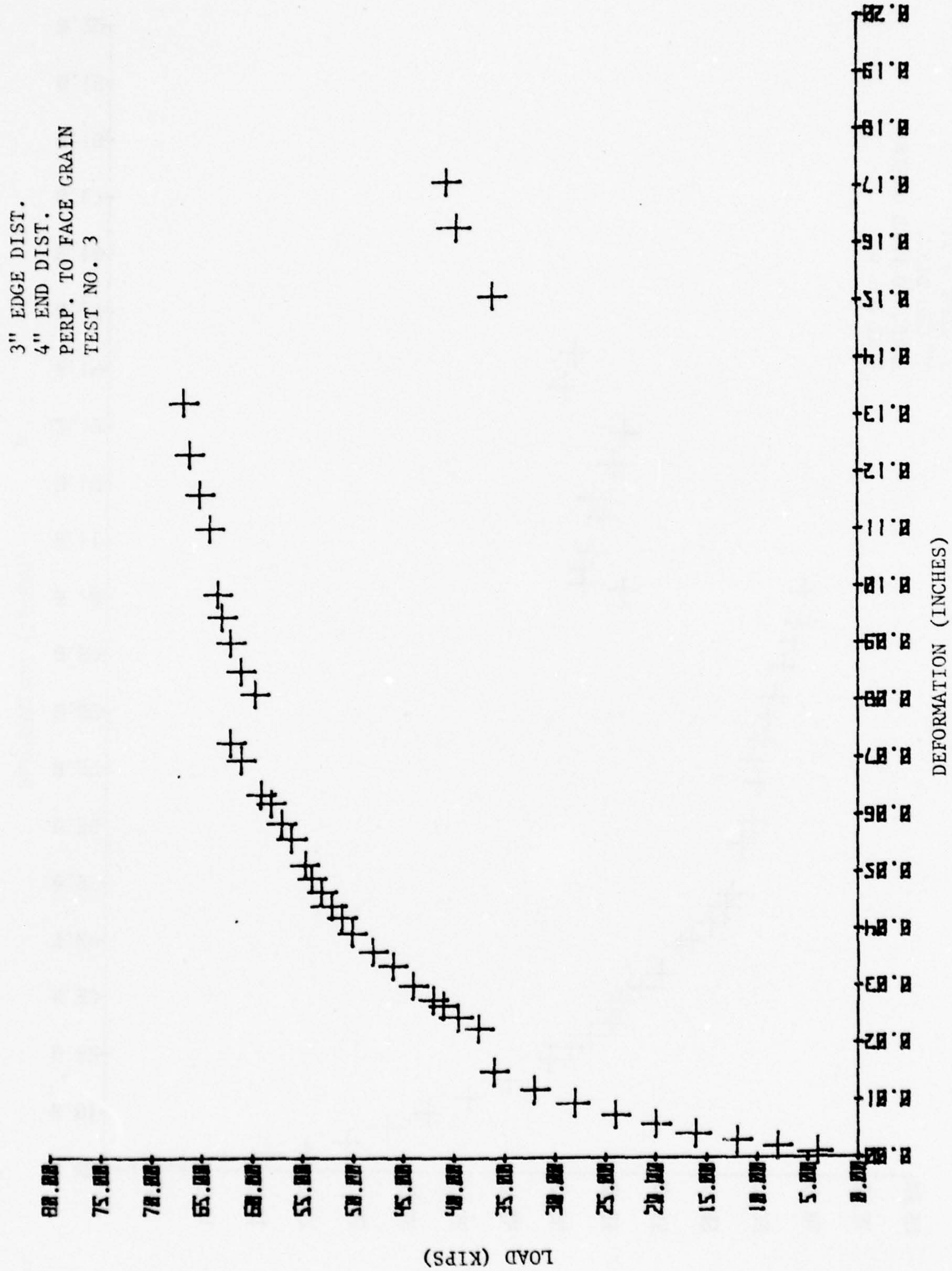

2.75" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 3
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00

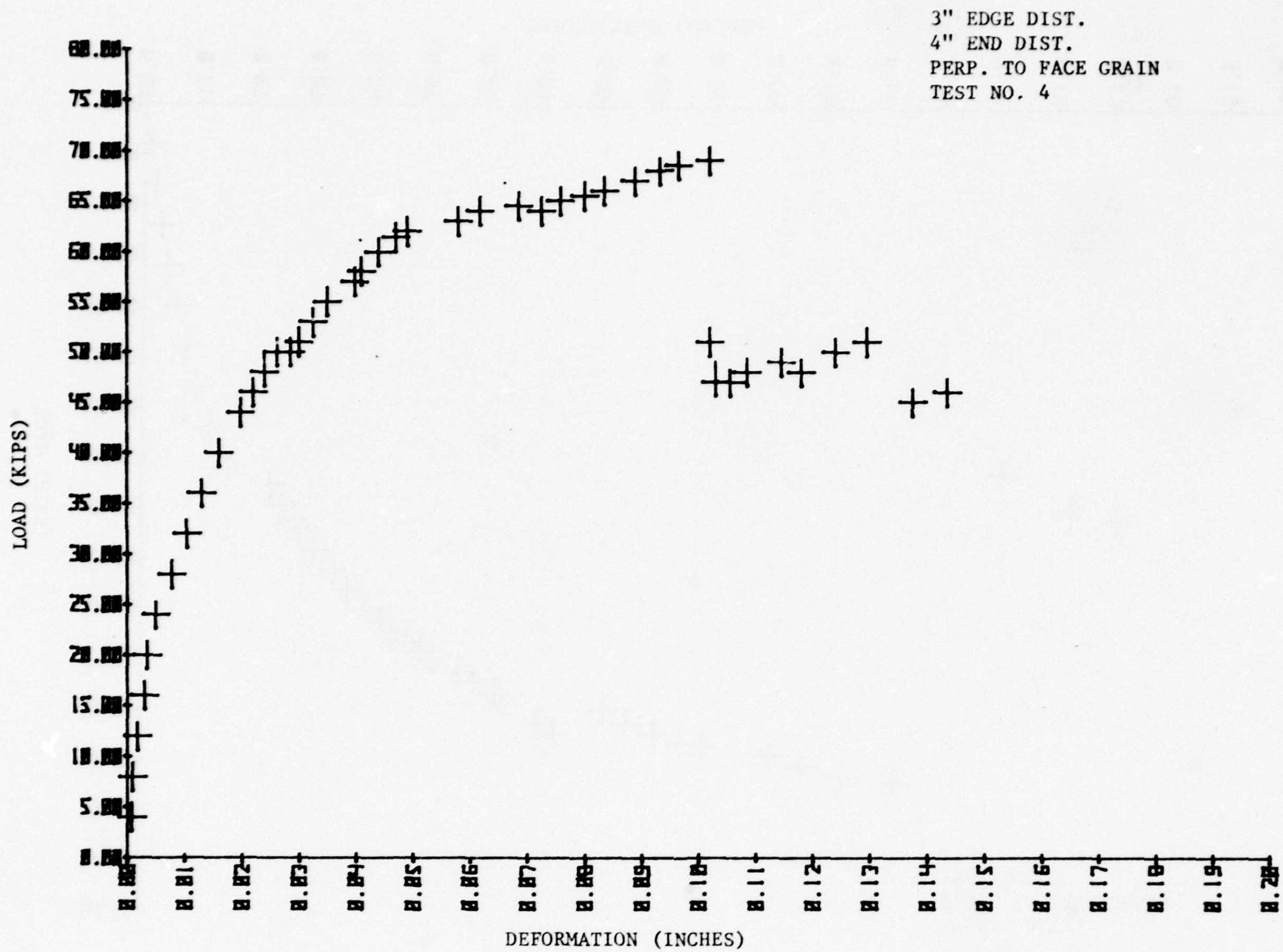

2.75" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 4
LOAD (KIPS)
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)

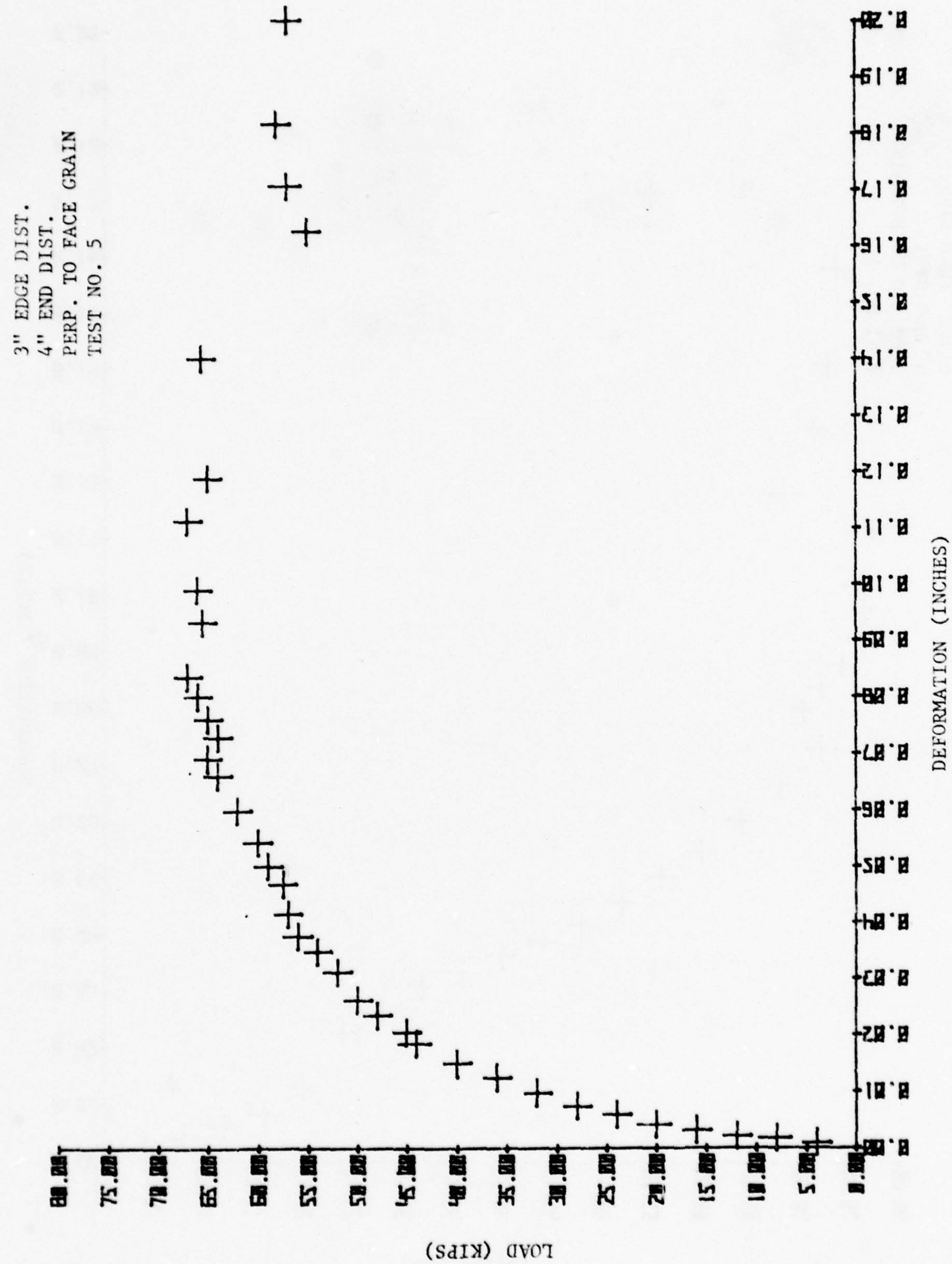

2.75" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 5
LOAD (KIPS)
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
DEFORMATION (INCHES)

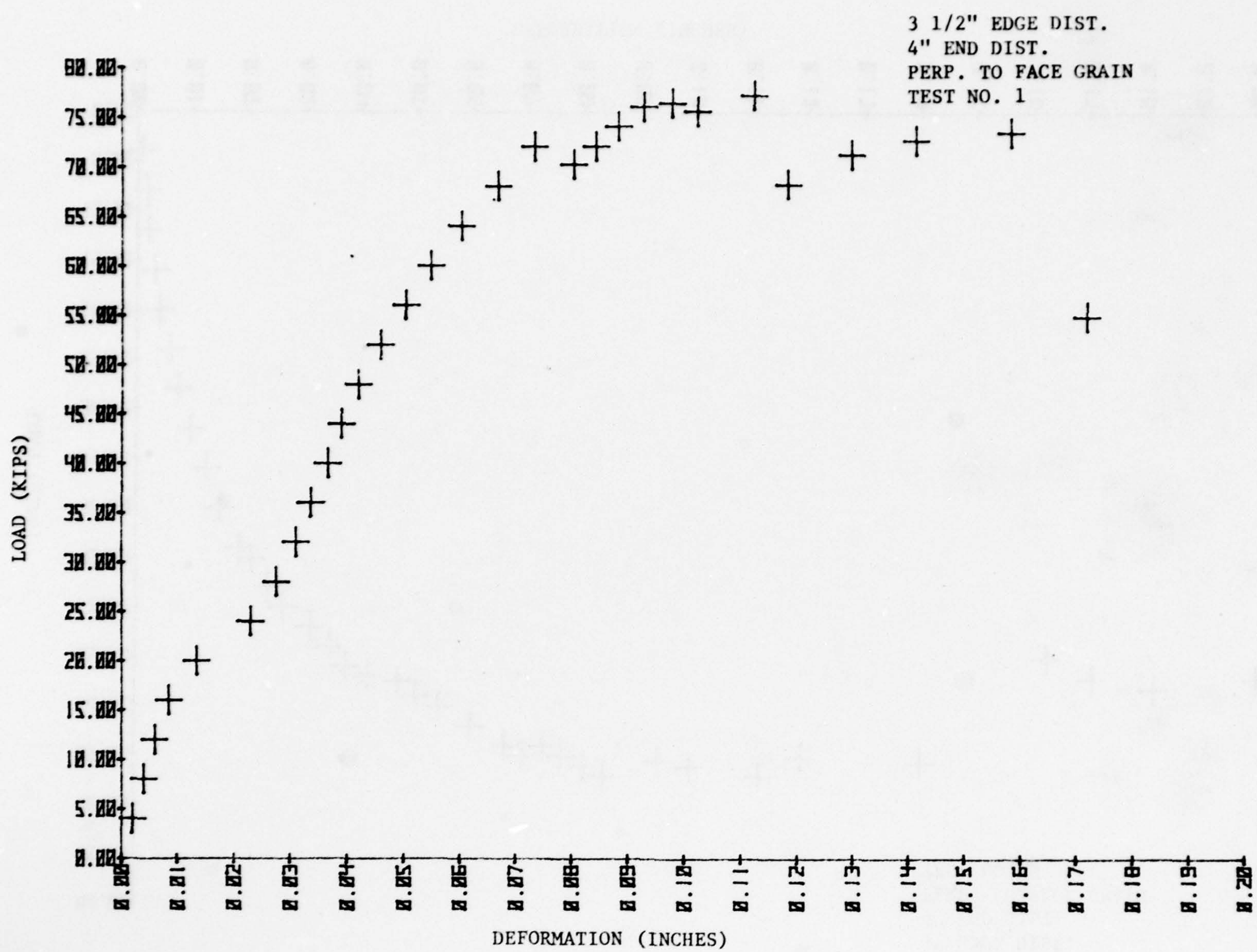

3" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 1
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00

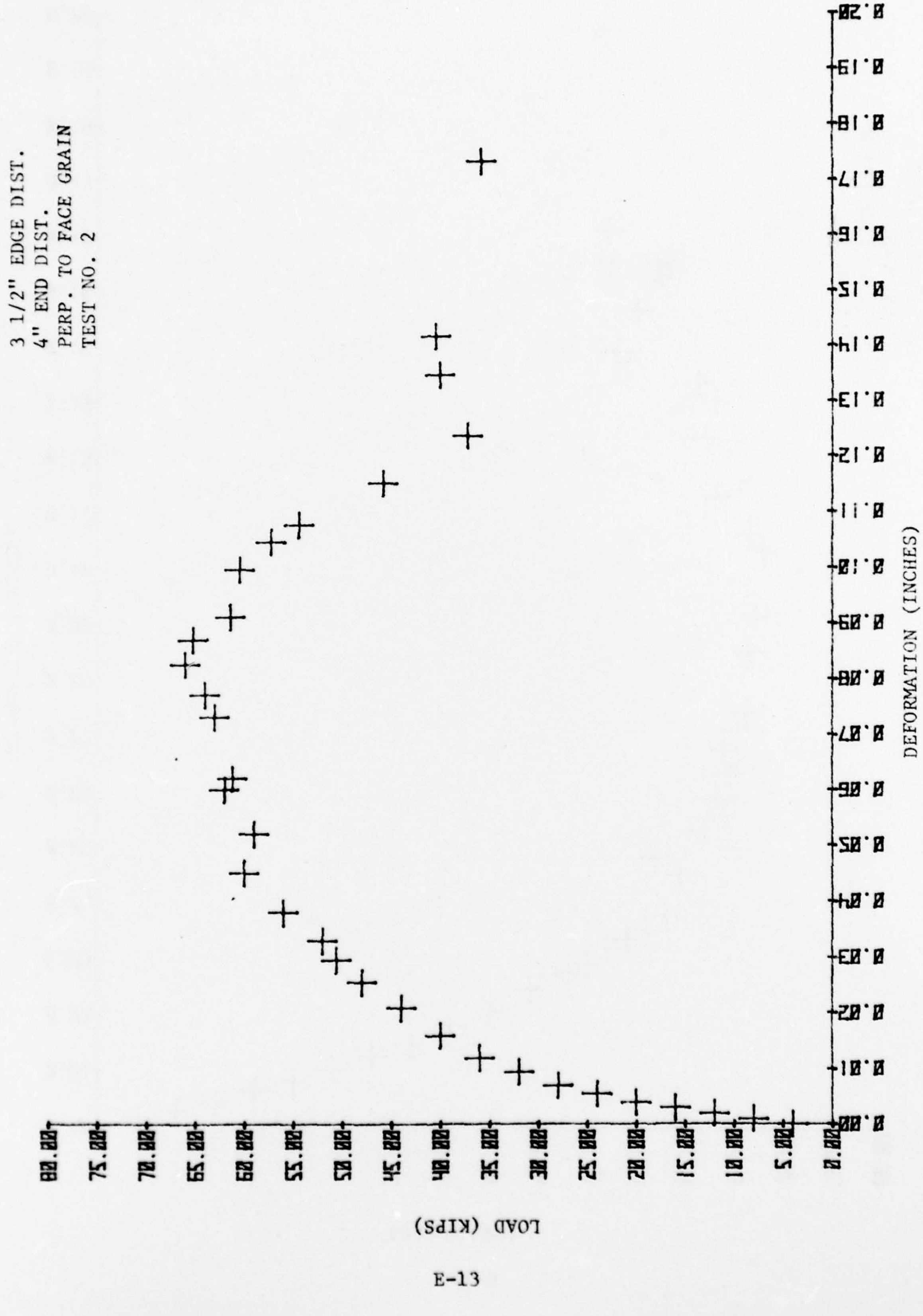

3" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 2
LOAD (KIPS)
DEFORMATION (INCHES)

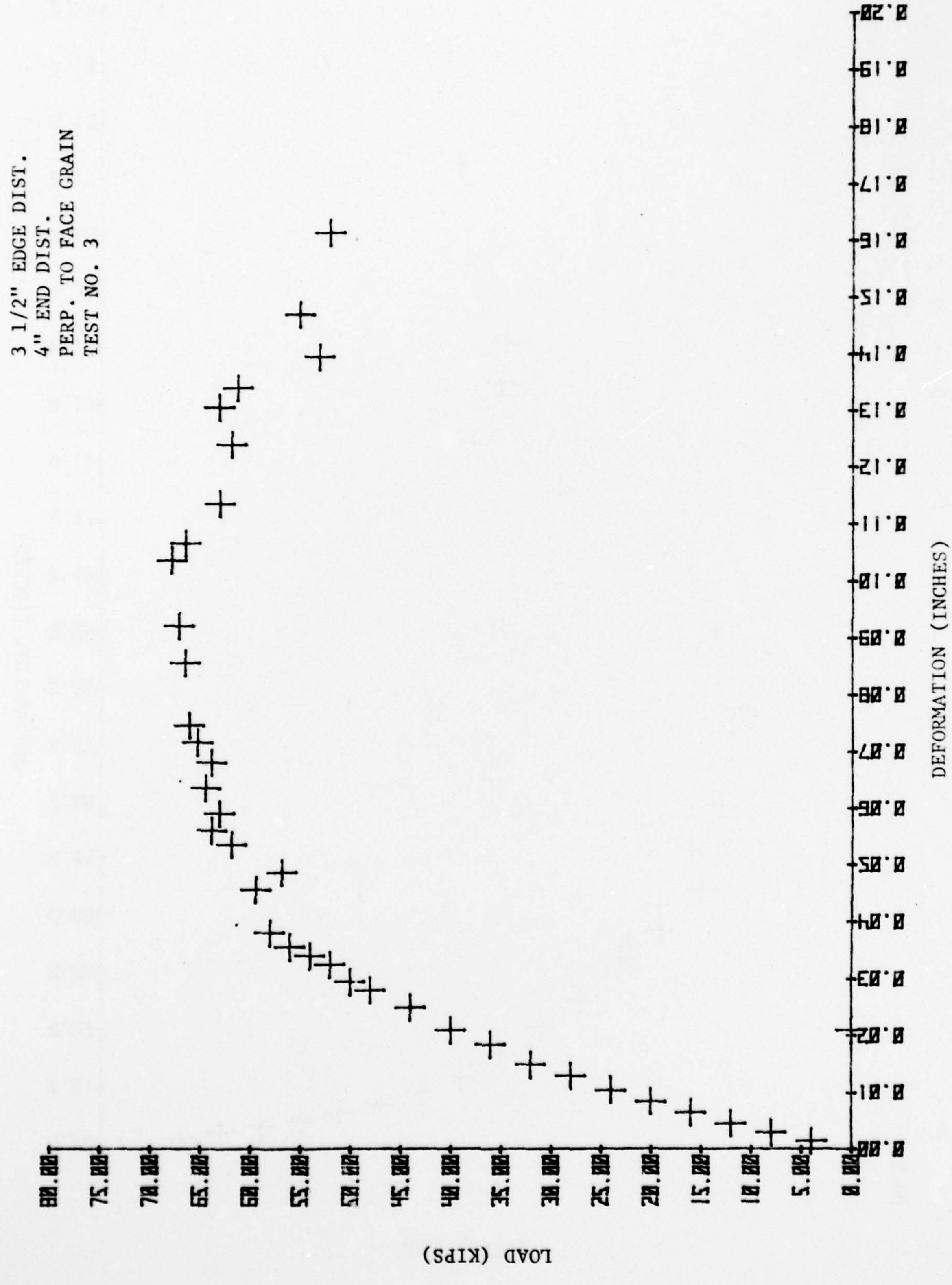

3" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 3
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00

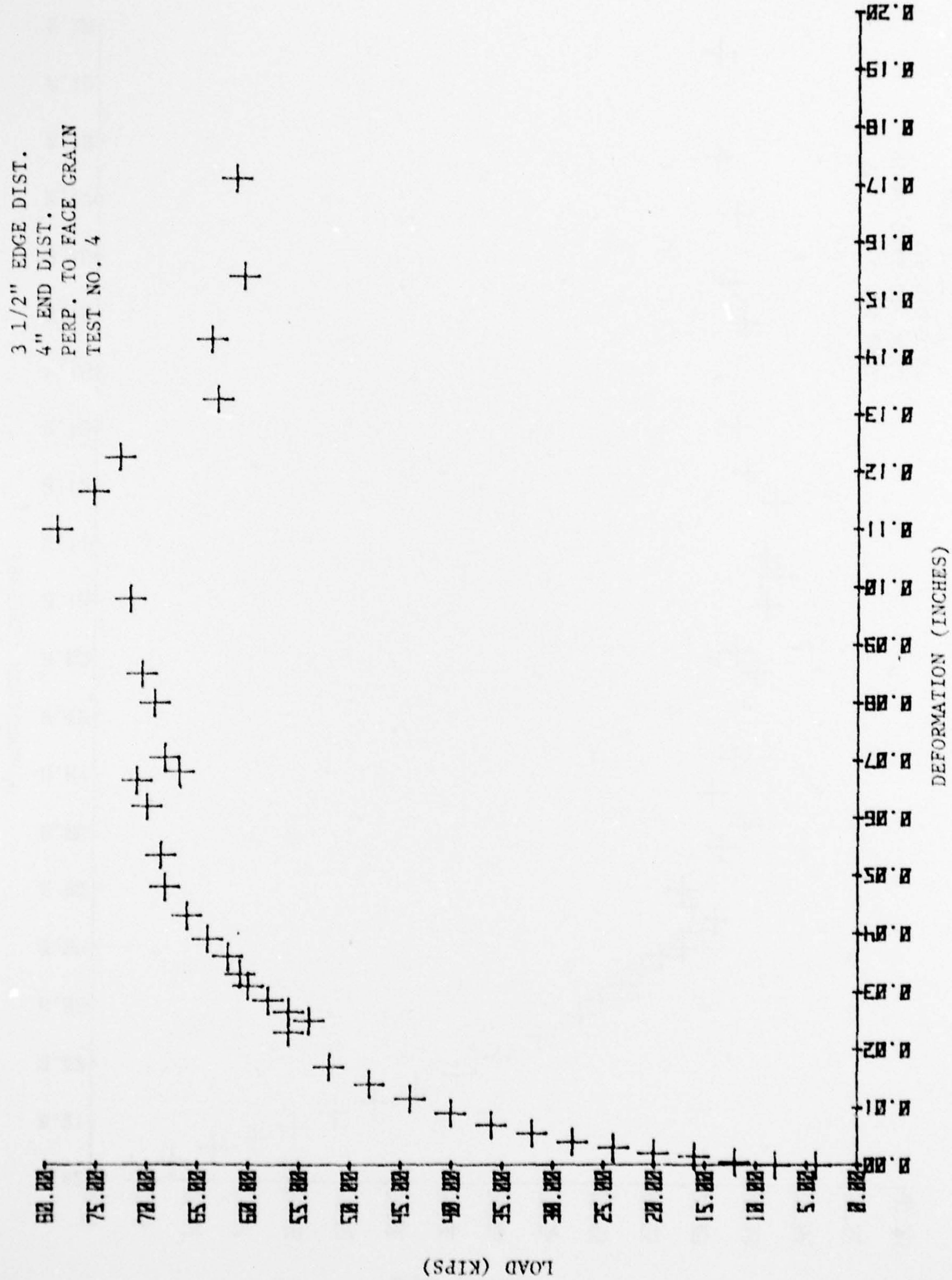

3" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 4
LOAD (KIPS)
DEFORMATION (INCHES)

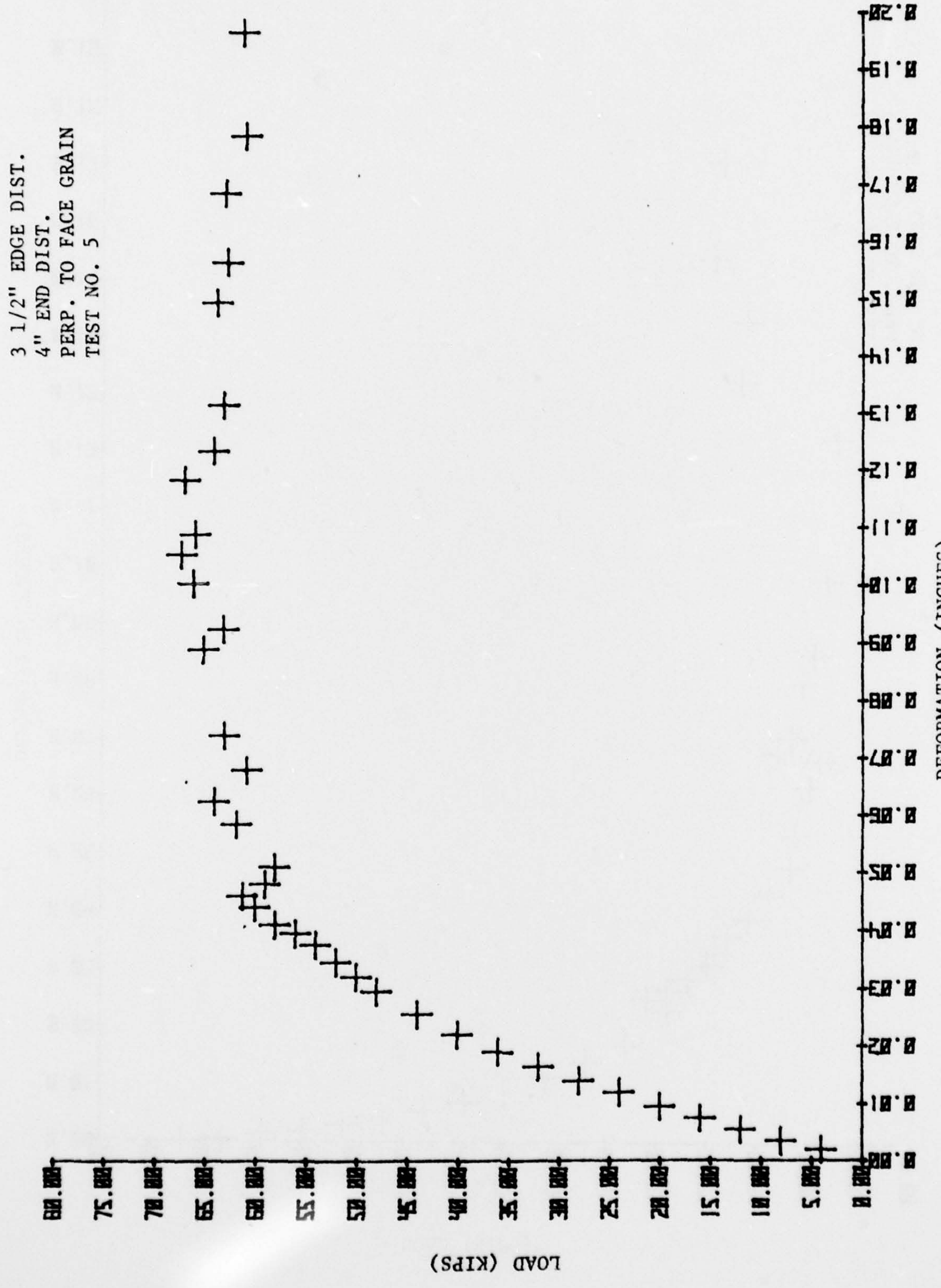

3" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 5
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00

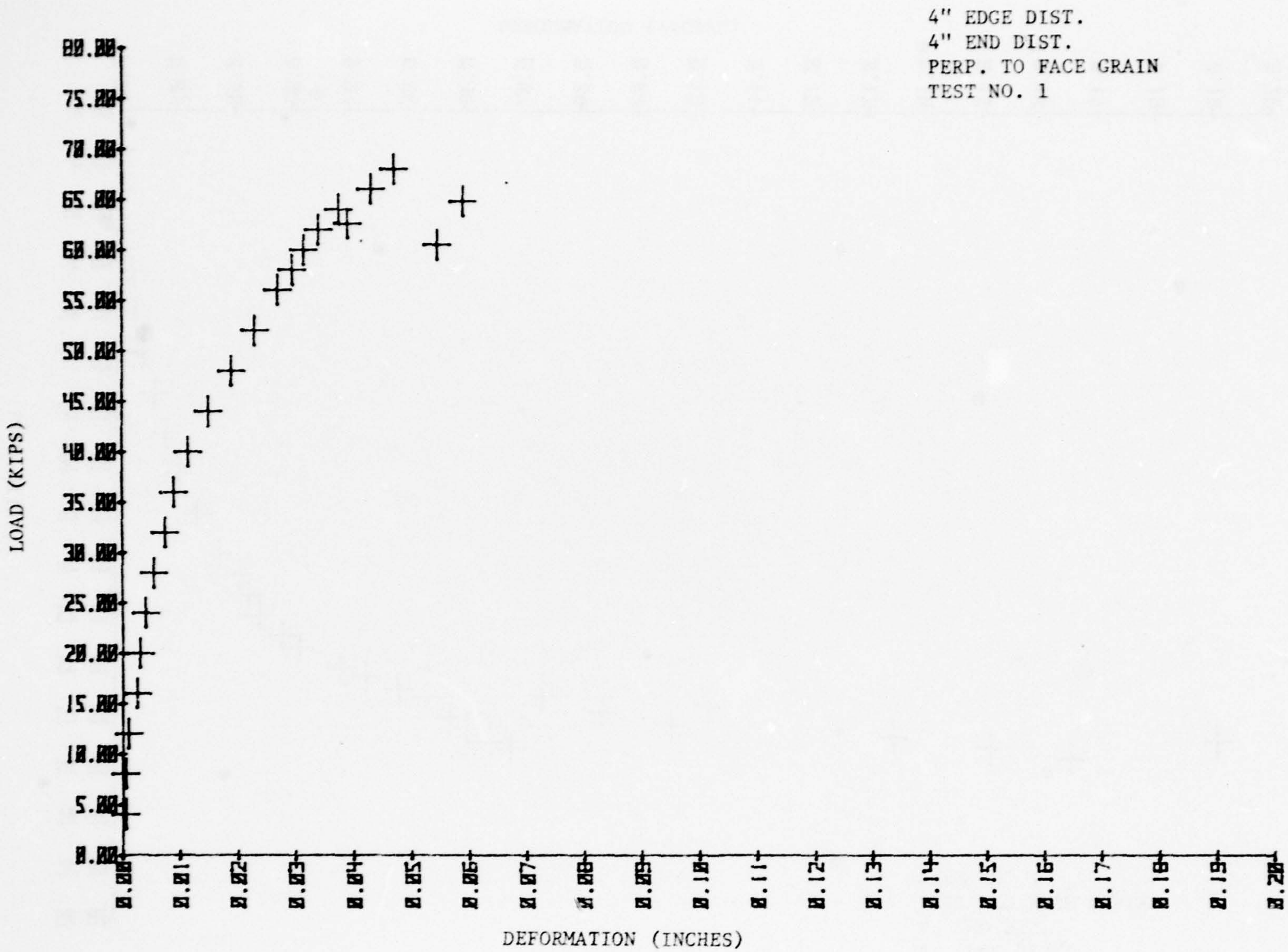

3 1/2" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 1
LOAD (KIPS)
DEFORMATION (INCHES)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20

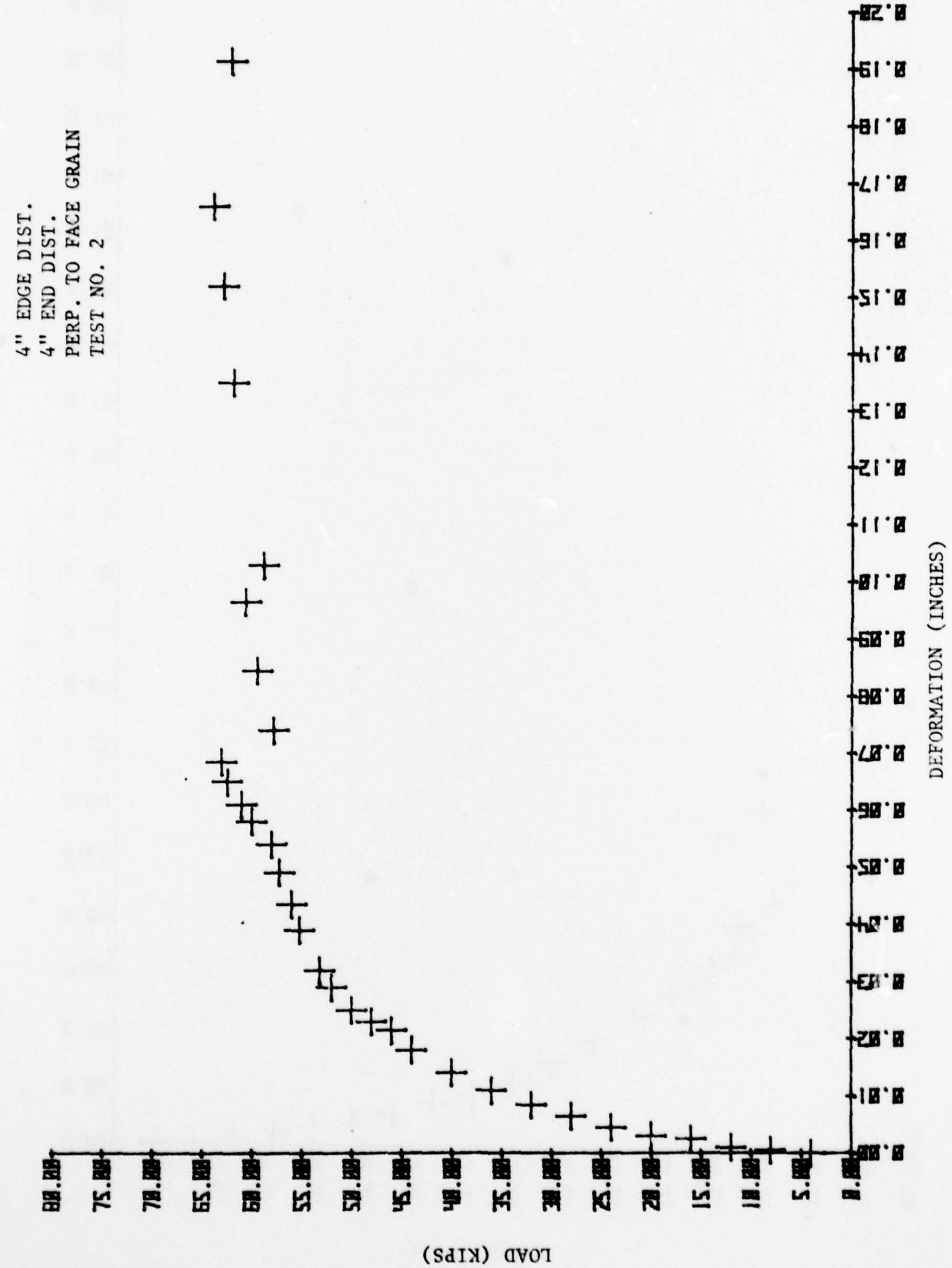

3 1/2" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 2
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00

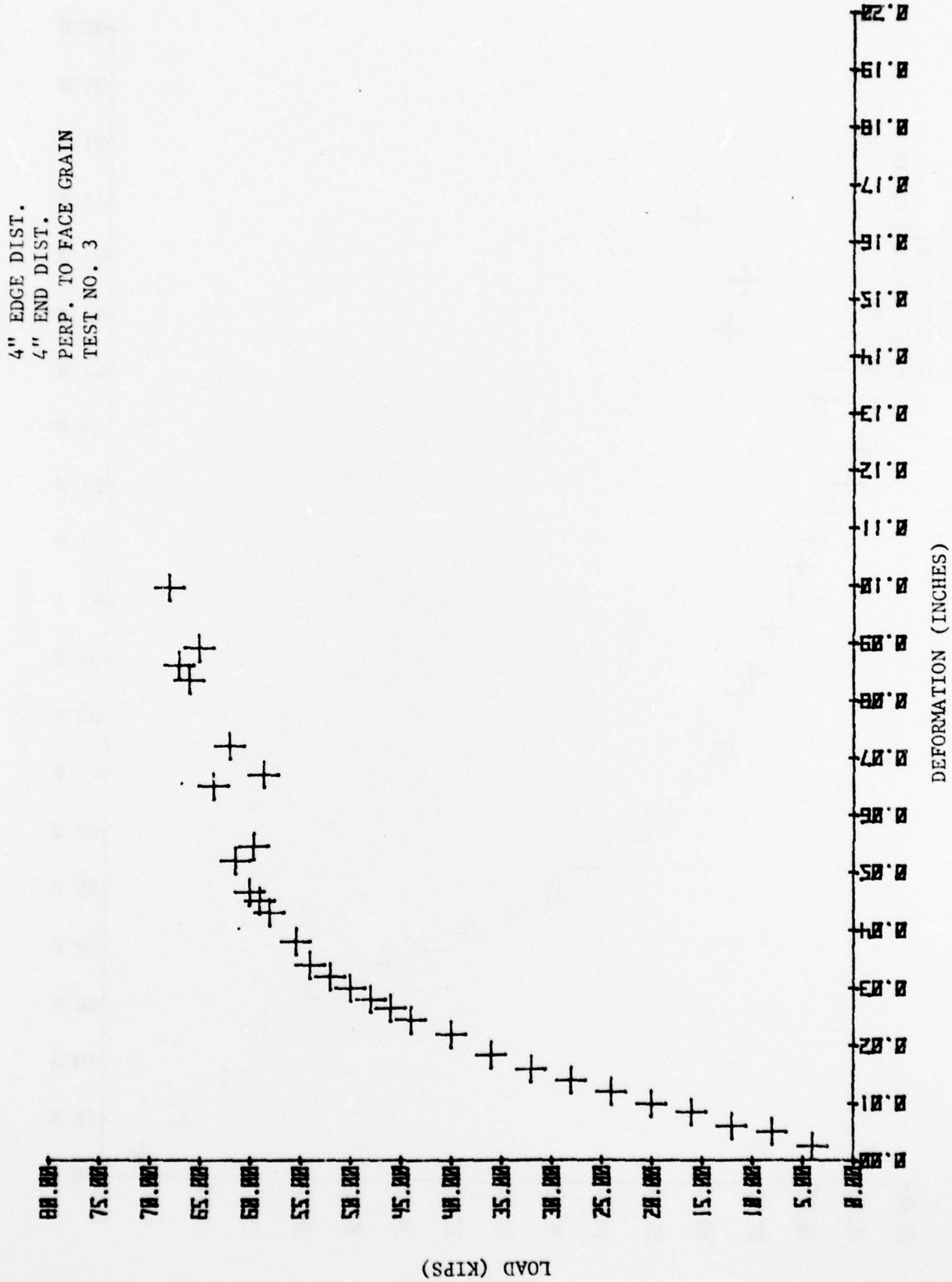

3 1/2" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 3
DEFORMATION (INCHES)
LOAD (KIPS)
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19 0.20
0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00 50.00 55.00 60.00 65.00 70.00 75.00 80.00


3 1/2" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 4
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00

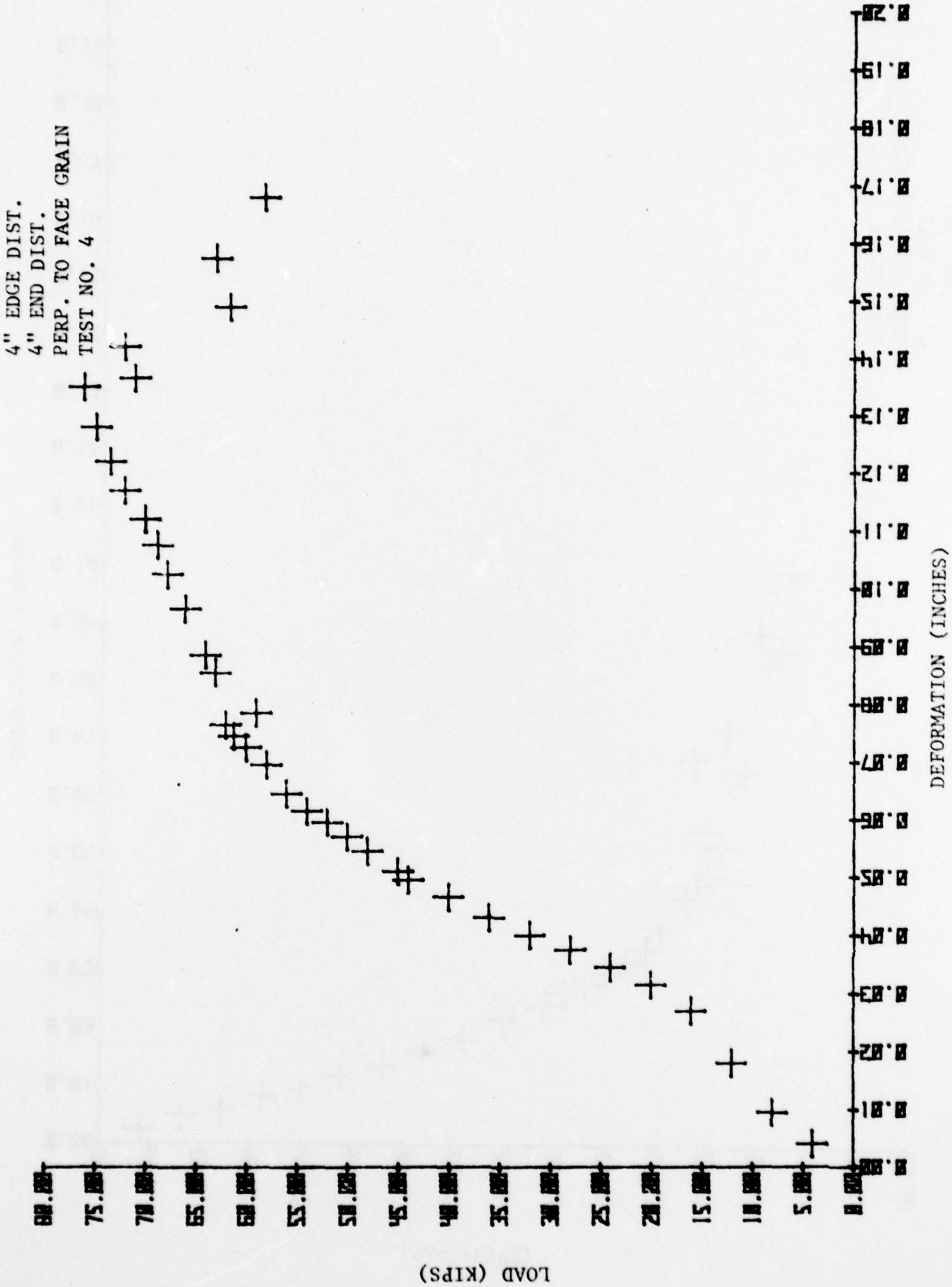

3 1/2" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 5
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20


4" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 1
LOAD (KIPS)
DEFORMATION (INCHES)

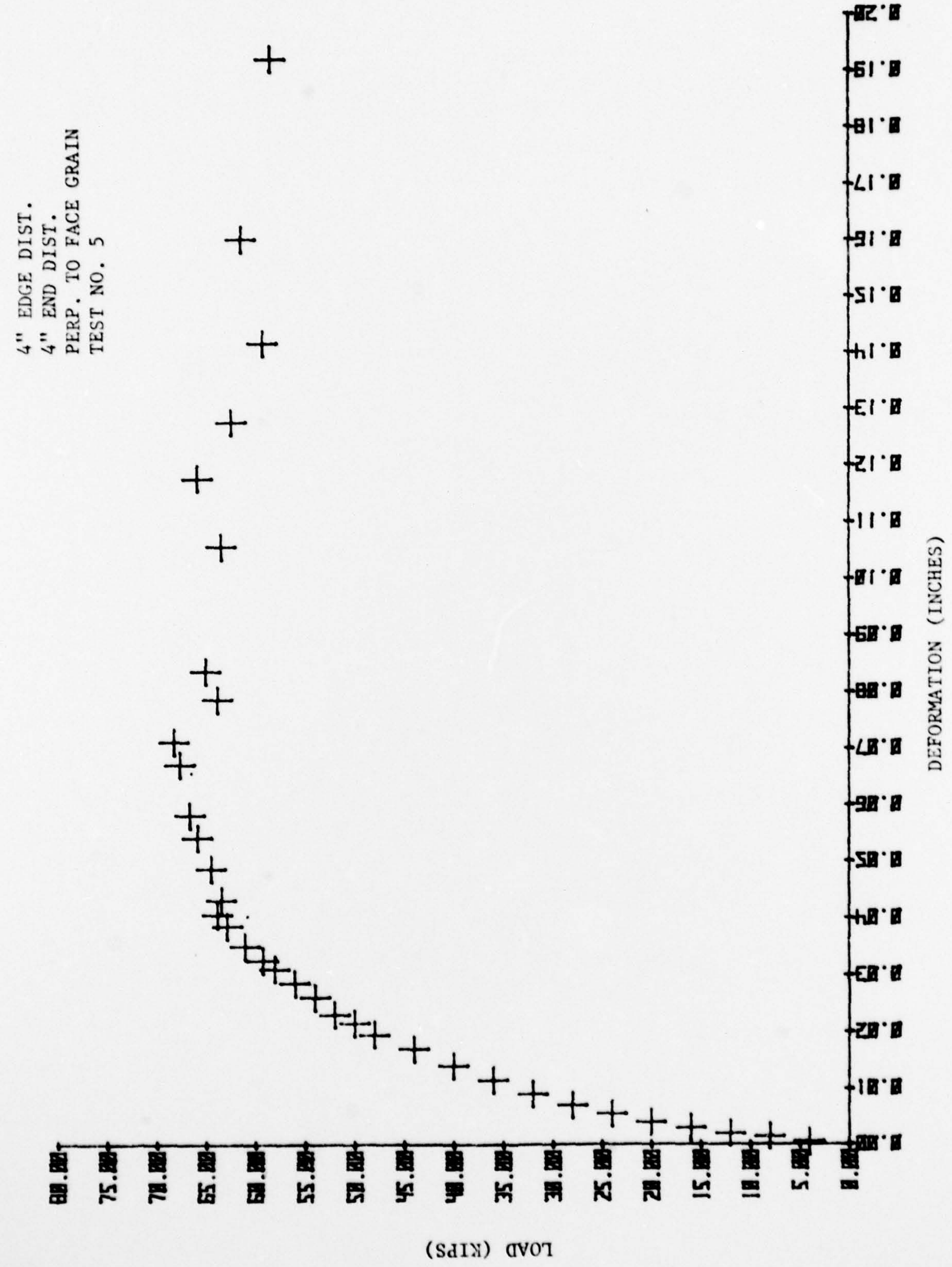

4" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 2
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00



4" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 3
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00

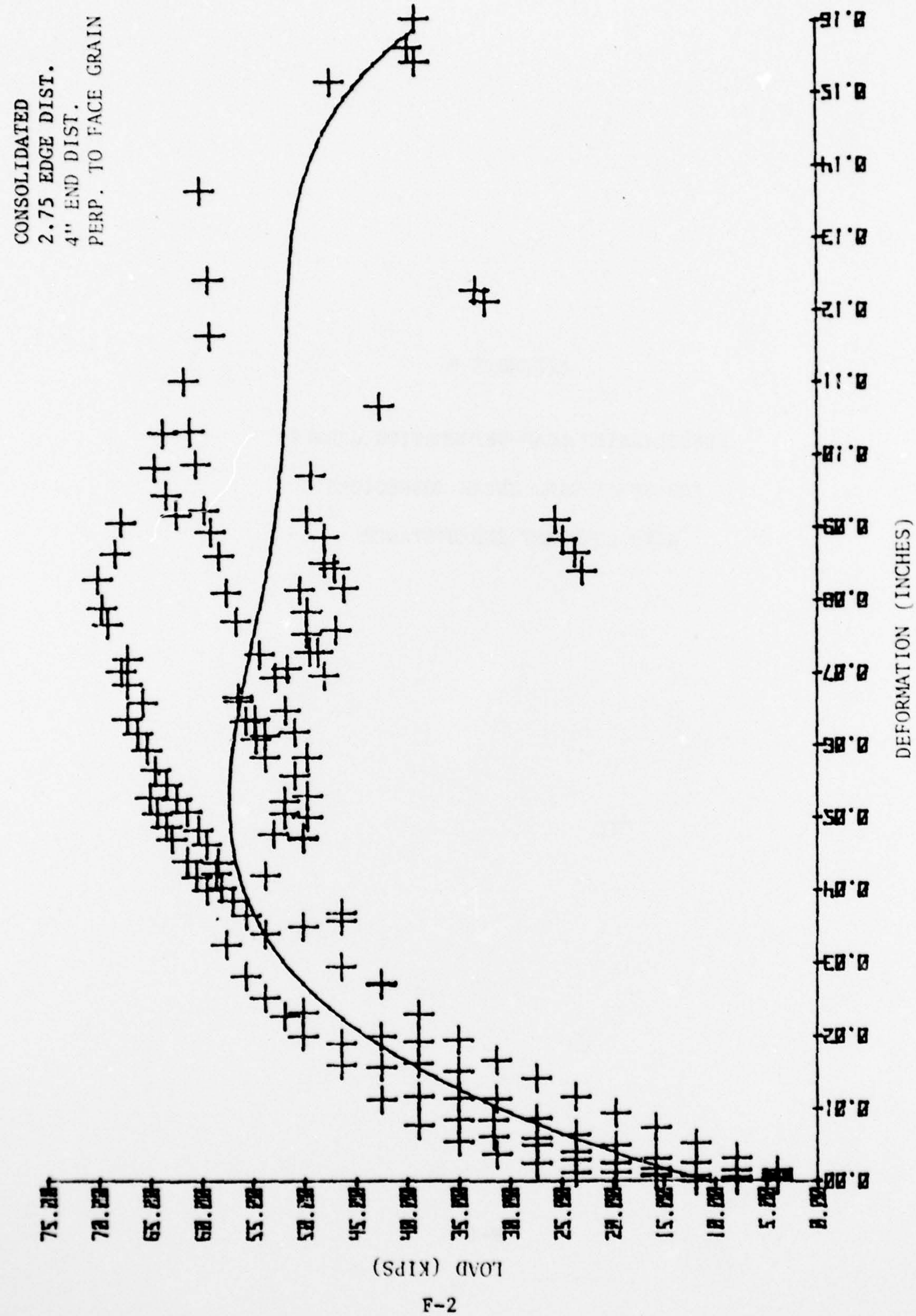


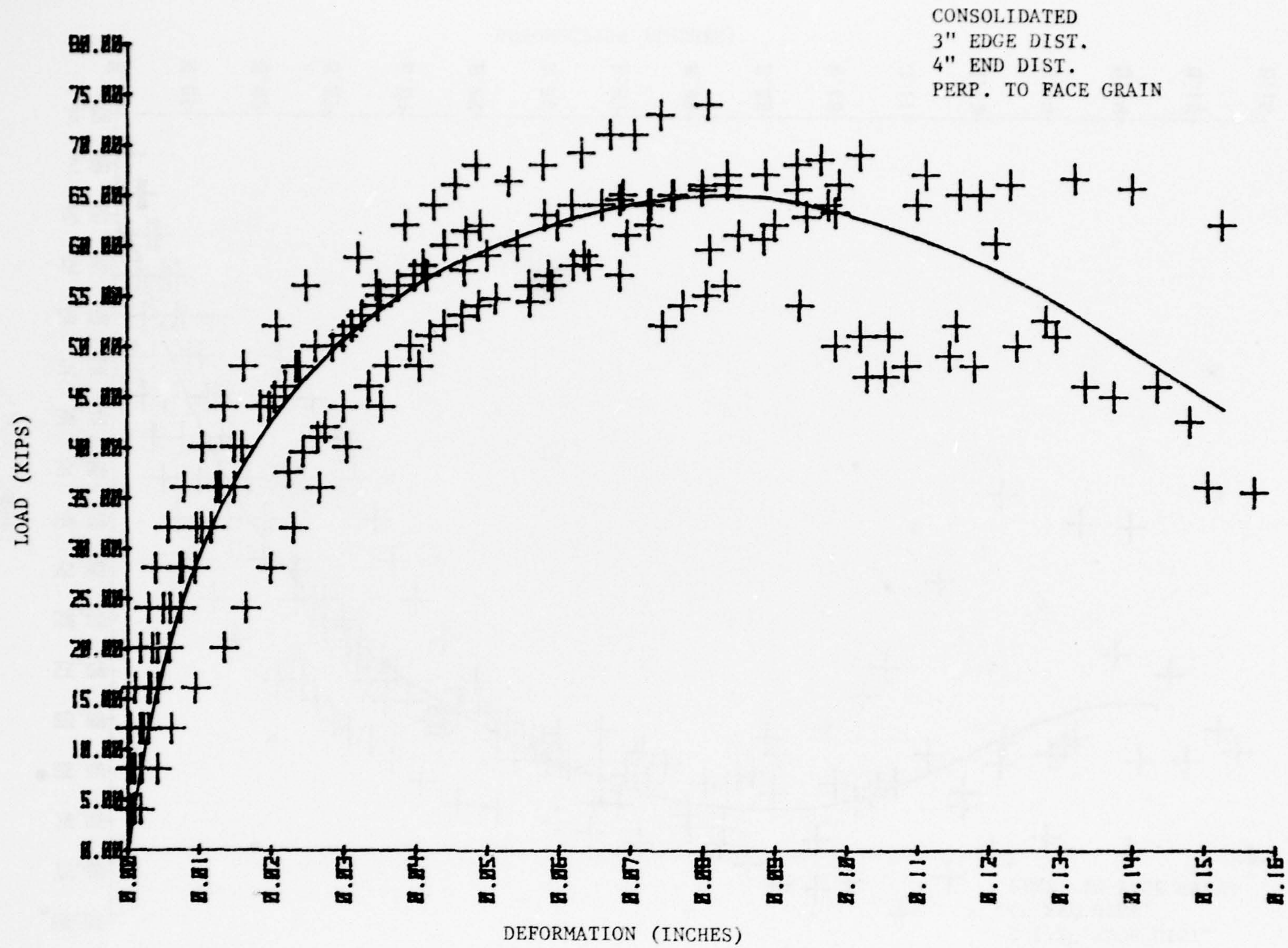
4" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 4
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00

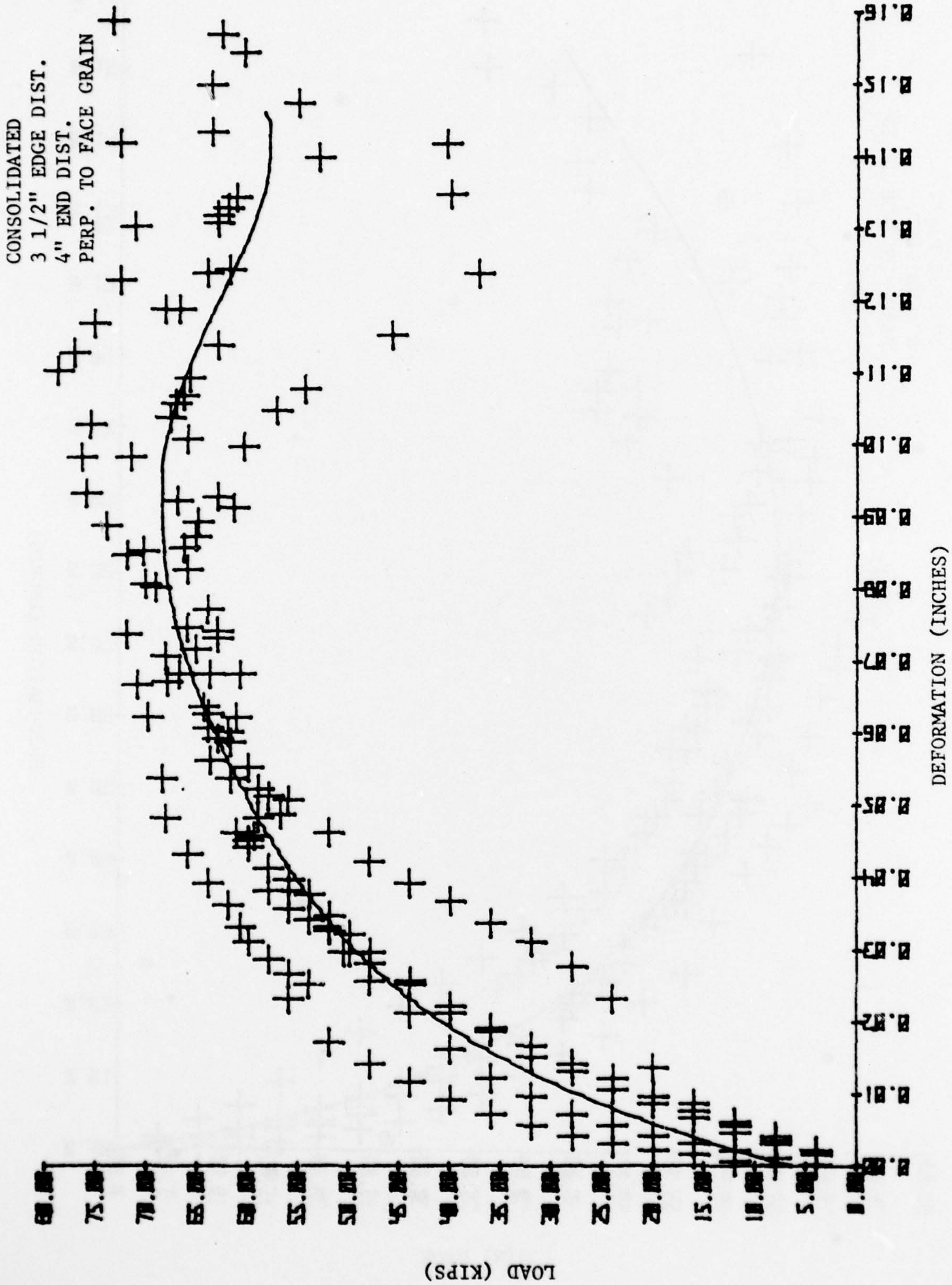

4" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
TEST NO. 5
DEFORMATION (INCHES)
LOAD (KIPS)

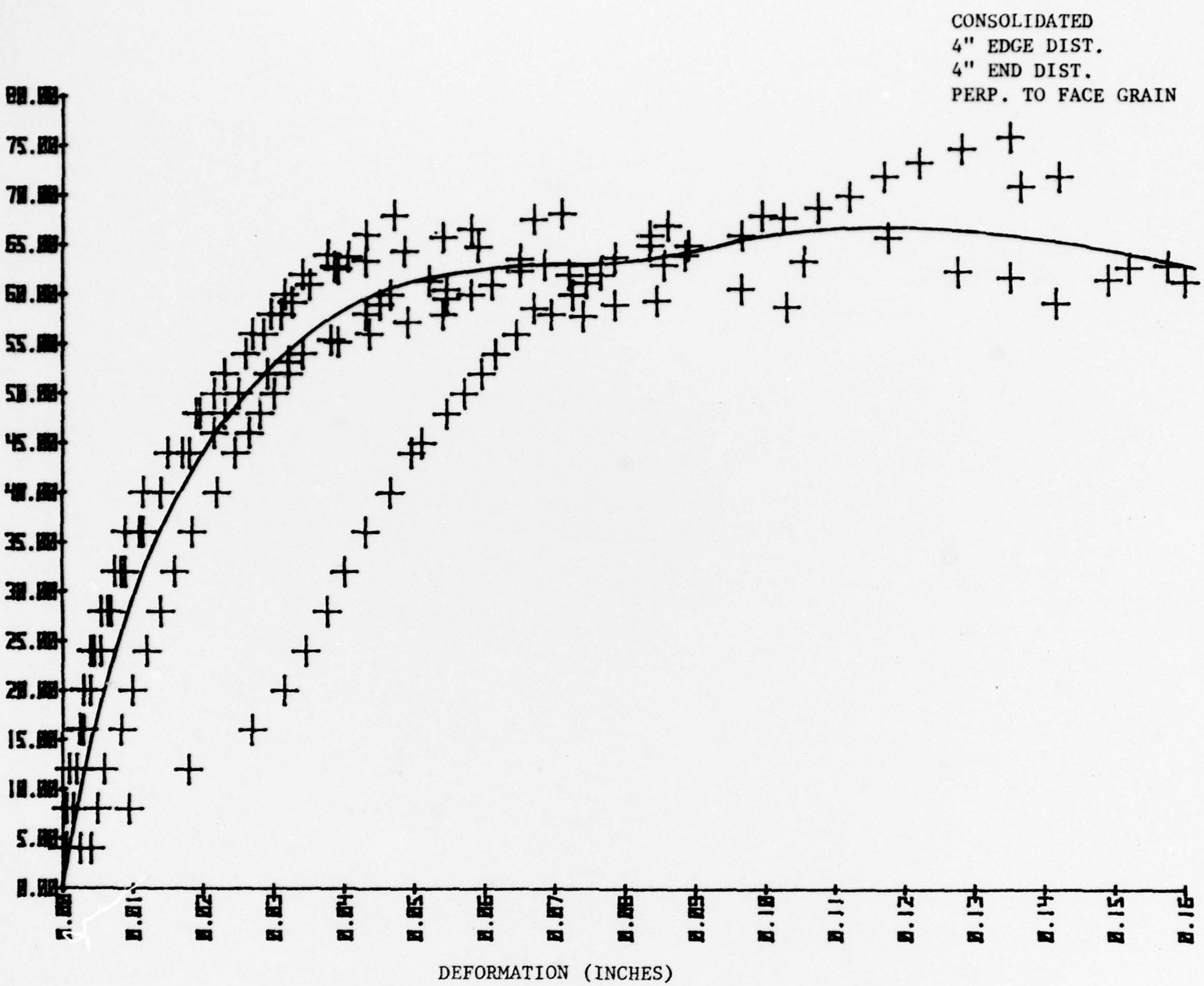
APPENDIX F

CONSOLIDATED LOAD-DEFORMATION CURVES FOR SPLIT-RING SHEAR CONNECTORS WITH CONSTANT END DISTANCE


CONSOLIDATED
2.75 EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00


CONSOLIDATED
3" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00
DEFORMATION (INCHES)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16


CONSOLIDATED
3 1/2" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
DEFORMATION (INCHES)
LOAD (KIPS)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00


CONSOLIDATED
4" EDGE DIST.
4" END DIST.
PERP. TO FACE GRAIN
LOAD (KIPS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
55.00
60.00
65.00
70.00
75.00
80.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0.14
0.15
0.16
DEFORMATION (INCHES)